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Marshall Space Flight Center, Alabama 35812

LAUNCH DEPLOYMENT ASSEMBLY HUMAN ENGINEERING ANALYSIS

Prepared for:
Science and Engineering Directorate
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Training and Crew Systems Division
Systems Branch by:



SIGMATECH, INC.

SIGMATECH	Launch Deployment Assembly Human Engineering Analysis DECEMBER 1996 EO66 (96-21)
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Prepared By:

T. Loughead 1-28-97
T. Loughead/Sigmattech Date

Approved By:

C. Dischinger 29 JANUARY, 1997
C. Dischinger/EO66 Date

G. Hullett-Smith 1-30-97
G. Hullett-Smith/EO66 Date
Chief, Systems Branch

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Sigmattech, Inc.
6000-N Technology Drive, Huntsville, Alabama 35805-1955

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ACRONYMS AND ABBREVIATIONS

APFR	Articulating Portable Foot Restraint
CDR.....	Critical Design Review
EDF.....	Expandable Diameter Fastener
EVA	Extravehicular Activity
FRGF.....	Flight Releasable Grapple Fixture
FSE.....	Flight Support Equipment
FSEGF.....	Flight Support Equipment Grapple Fixture
IVA.....	Intravehicular Activity
LCA.....	Lab Cradle Assembly
LDA.....	Launch Deployment Assembly
LDP.....	Launch Deployment Package
LSA.....	Launch Support Assembly
MSFC.....	George C. Marshall Space Flight Center
MTSAS-P.....	Module to Truss Structure Attachment System-Passive
NASA.....	National Aeronautics and Space Administration
NBS.....	Neutral Buoyancy Simulator
ORU	Orbital Replacement Unit
PAD.....	PFR Adapter Device
PDGF.....	Power Data Grapple Fixture
SLP.....	Spacelab Logistics Pallet
SRMS.....	Shuttle Remote Manipulator System
SSRMS.....	Space Station Remote Manipulator System
STS	Shuttle Transportation System
UHF.....	Ultra High Frequency
WIF.....	Worksite Interface

1.0 INTRODUCTION

This report documents the human engineering analysis performed by the Systems Branch in support of the 6A cargo element design. The human engineering analysis is limited to the extra vehicular activities (EVA) which are involved in removal of various cargo items from the LDA and specific activities concerning deployment of the Space Station Remote Manipulator System (SSRMS) as required in the LDA End Item Specification (MSFC-SPEC-2534).

2.0 OBJECTIVE

The objective of the LDA Human Engineering Analysis was to determine the extent to which the current configuration of the LDA design meets the human engineering requirements specified in MSFC-SPEC-2534. These requirements were derived from NASA-STD-3000 and SSP 50005.

The requirements listed in MSFC-SPEC-2534 which were examined in this analysis include:

- To provide unobstructed EVA access for removal of the Rigid Umbilical.
- To provide unobstructed EVA access for removal of the UHF Antenna and Deployment Assembly.
- To provide unobstructed EVA access for removal of the LCA.
- The orientation of the EVA foot restraint sockets shall support access to the cargo item worksites required for cargo item removal.
- The orientation and location of the EVA handrails with tether points shall support EVA translation and access to the cargo item worksites required for cargo item removal.
- The FRGF adapter design shall mount the FRGF in a location and orientation which allows unobstructed EVA access for task requirements.

- The SSRMS Utility Cable Restraint Assembly shall restrain the SSRMS Utility Cable without obstructing EVA access for task requirements.
- The SSRMS Launch Restraint Bolt Landing Assembly shall provide the return stowage of the SSRMS Launch Restraint Bolt Assemblies without obstructing EVA access for the task requirements.

3.0 APPROACH

3.1 Modeling Methodology:

All of the analysis was performed using models assembled in Jack¹ (Version 5.9) , a human factors program developed by the University of Pennsylvania. Models in IGES or DXF format were converted to the Jack format on the SGI platform. Additional items such as crew aids and visual features were constructed within Jack using the CAD feature with dimensions obtained from appropriate standards, ICDs, and other program documents.

The following describes the method of modeling each of the features of the LDA. Further description of each of the items can be found in the Launch Deployment Assembly Neutral Buoyancy Development Test Report (EO66 (06-09)).

3.1.1 Cargo Items and Flight Support Equipment (FSE):

Structural models of the LSA, SLP, SSRMS, Module to Truss Structure Attachment System-Passive (MTSAS-P), UHF Antenna and Deployment Assembly, and PDGF Rigid Umbilical originated with the Cargo Item Developers and were obtained by EO66 from Bobby Lawson/ED54 and Barbara Breithaupt/EP44 in the EMS format. The

¹ Jack is a registered trademark of a program which displays and manipulates articulated geometric figures and was devised by the Computer Graphics Laboratory, Department of Information Sciences, University of Pennsylvania, Philadelphia, Pennsylvania.

size of each of the files was reduced by deleting internal structures and external features which were not necessary for the analysis and by breaking the files into smaller parts. The models were then translated into IGES format and transferred to the Silicon Graphics platform where a second conversion was made into the Jack software format and the models were reassembled.

The model of the UHF Antenna Assembly was incomplete as obtained, consisting only of the MSFC furnished interface points and the two cylindrical antenna elements. A more complete model was obtained later, but unfortunately the conversion to IGES format was not successful. An envelope model was then constructed within the Jack software with dimensions obtained from McDonnell Douglas Drawing number 1F7167.

The LCA model used in the previous analysis was primarily for illustration purposes as the final version was not available. A model of the final version of the LCA was obtained from Boeing, but an attempt to reduce the file size and translate into the Jack format was not successful. For the deployment envelope analysis, a simple model was constructed in Jack to the maximum external dimensions of the LCA. For the unstowing operations (LC1 and LC2), a simple envelope model was constructed in the Jack CAD package using the exterior dimensions obtained from drawings furnished by Boeing in the LCA CDR package (Boeing Drawing Numbers 683-11071 and 683-11073).

3.1.2 APFR and Space Suit:

A model of the APFR was obtained from JSC in IGES format. The APFR model was given articulated joints with joint limits imposed per published APFR data also obtained from JSC. The suited subject was replaced by a representation of the reach envelope appropriately placed to simulate the reach envelope of 5th and 95th percentile male subjects (see Section 3.1.4).

3.1.3 Crew Aids:

Models of handrails, handholds, WIFs, and other crew aids and interfaces were constructed either directly in the Jack software or on another CAD platform and transferred into Jack. These dimensions were obtained from EVA Standard ICD (SSP 30256:001E).

3.1.4 Reach and Visual Envelopes:

A model of the EVA Reach envelope of 5th and 95th percentile males was derived from NASA-STD-3000 and attached to a model of the APFR. The 5th percentile data were used as the ideal two-handed reach envelope for all subjects. The simplified model allowed a rapid manipulation of the APFR to bring the reach envelope of the space-suited subject within a target area. An additional model was developed which provided a 50th percentile space suited figure with the 5th and 95th percentile reach envelopes attached to the front of the suit. This allowed a visual evaluation of clearance as well as reach envelope.

The Jack software has a visual envelope feature which was not used because the tasks involved no visual obstructions at the Worksite. It was assumed that the visual envelope defined in NASA-STD-3000 Figure 14.3.2.3.1-2 was inclusive of the 5th percentile one-handed reach envelope defined in Figure 14.3.2.3-1.

3.1.5 Other Hardware Models:

Models such as a cylindrical representation of the dynamic envelope of the Space Shuttle and visual features of the SLP were constructed within the Jack software with dimensions obtained from the Spacelab Pallet Accommodation Handbook Appendix B (SLP/2104-2).

4.0 ANALYSIS

The following is a list of the EVA activities analyzed and the method used for each. For the purpose of analysis the dimensions used were those listed in MSFC-SPEC-2534 which were extracted from NASA-STD-3000 Volume IV, and SSP 50005 Rev. A.

4.1 TRANSLATION PATHS:

Four major translation paths were identified: Longitudinal ($\pm X_p$) Port and Starboard and trans-axial Port-Starboard ($\pm Y_p$) Forward and Aft. Translation paths were analyzed by placing a cylindrical representation of the envelope along the handrails which define the above translation paths.

An additional translation path between the SLP and the ISS Lab module will be used in conjunction with activities involving the installation of additional Lab hardware. Because translation between the ISS Lab and the SLP is not the responsibility of the SLP CE Integrator, this was not examined. However, the ICD-defined distance of 48 inches between the SLP and the Lab at the tangent point of the Lab will allow ample room for work, and the design of the MTSAS-P Adapter will provide ample handholds of opportunity along the MTSAS-P Adapter. Handholds of opportunity are structural features such as struts which may be used as handholds at the discretion of the crew member.

4.2 WORK ENVELOPES:

Work envelope for this analysis was considered to consist of two major components: arm/hand reach envelope and body clearance envelope. An additional requirement is that ample tool clearance be provided for the various EVA tasks.

4.2.1 Reach Envelope:

The reach envelope (Figure 4.2-1) is interpolated from Figure 14.3.2.3.1-1 of SSP 50005 Revision A. (Figure 4.2-2). The dimensions were calculated as the farthest upper portion and the mid-section of the lower fifth percentile reach envelope tangent to an arc drawn with the center at the four bolt pattern of APFR boot plate. The distance was then determined between the APFR center point and a point 12" above and centered on the object which was to be manipulated (usually an EVA Bolt). See Section 4.3.1 - Tool Clearance Envelope.

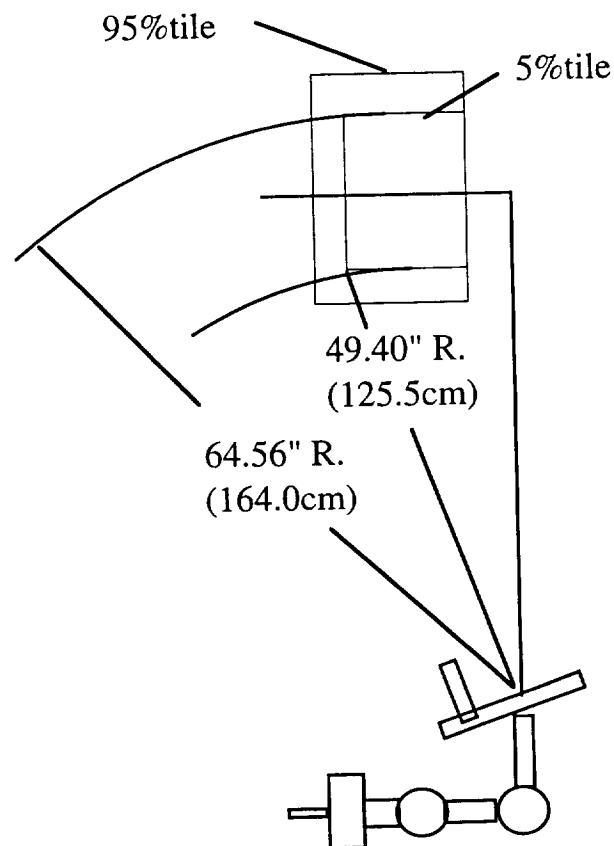


Figure 4.2-1 Reach Envelope Derived From SSP 50005A and NASA-STD-3000 (side view) .

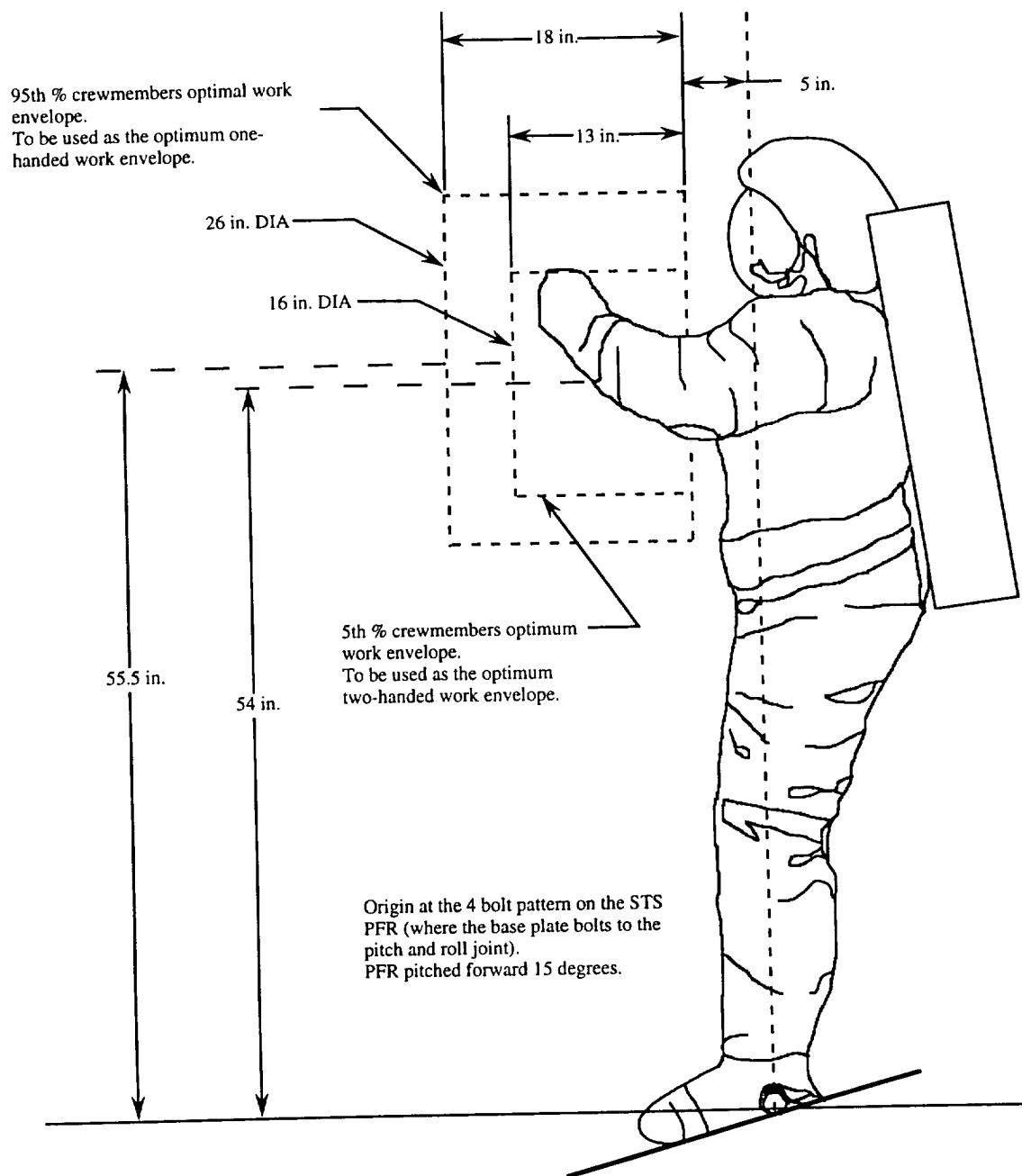


Figure 4.2-2 Reach Envelope (from Figure 14.3.2.3-1 Crew member Optimum Work Envelope- NASA-STD-3000/VOL1/REV B.)

The location of the WIF for each worksite (see Figure 4.2-3) was that used in the CDR design. Because the APFRs have four degrees of freedom in addition to location, the distance was calculated with the APFR in the settings used in the orientation in the WIF (clocking) and pitch only. The other two degrees of freedom (roll and yaw) are adjustable by the EVA Crew member without egressing the APFR.

An acceptable range for the calculated distance was the 5th percentile reach envelope shown in Figure 4.2-2 ($49.40'' < \text{distance} < 64.56''$). This reach envelope is considered optimal for two-handed operations. The approach of calculating the straight line distance was considered more conservative than manipulating the model of the APFR until the cylinder representing the reach envelope was within the target area. For many tasks (such as clutch manipulation and connector removal), the single-handed reach envelope of $44.7'' < \text{distance} < 72.3''$ may be considered adequate. For this analysis, the single-handed range of figures were used for target values.

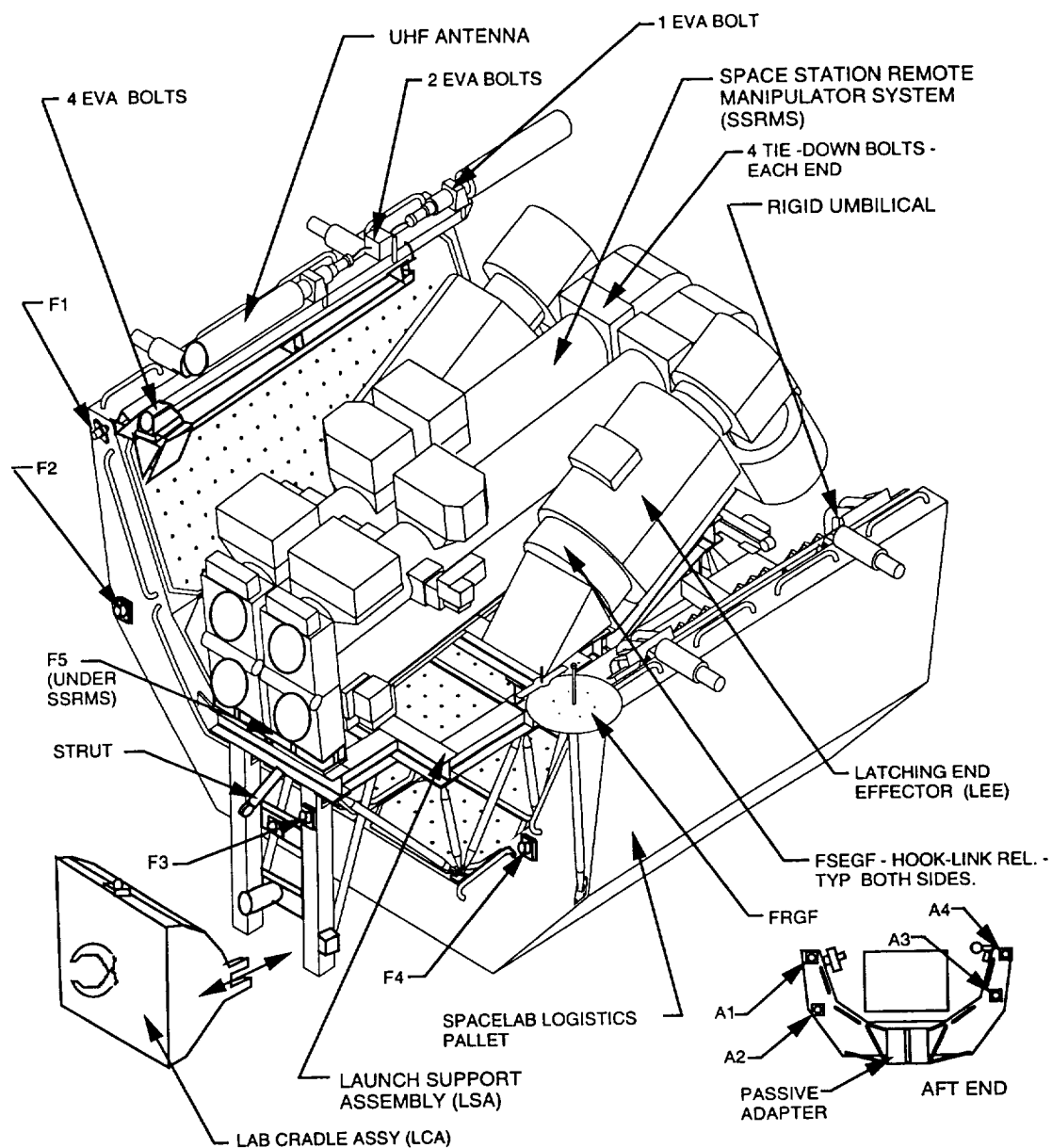


Figure 4.2-3 Configuration of LDA mounted to SLP showing sockets (WIFs) and Handrails/Handholds. (WIFs designated F_n are forward, WIFs designated A_n are Aft)

4.2.2 Body Clearance Envelope:

The body clearance envelope was considered as a gross cylindrical area of 48" diameter surrounding the Astronaut. Additional clearance for lower extremities is necessary and was not accounted for by the figure in Figure 4.2-2. For most of the EVA tasks, the worksites are located on a surface which does not require the crew member to manipulate between the worksite and another structural feature. This free space in back of the Astronaut will allow ample area for body clearance as determined by inspection.

4.2.3 Tool Clearance Envelope:

Tool clearance requirements are defined in paragraph 14.6.2.3 of NASA-STD-3000 and illustrated in Figure 4.2.3-1. For this analysis, a model was constructed which consisted of a torus with an inside diameter of 13.5" (the length of an Essex wrench) and an outside diameter of 16.5" which represents the required tool handle clearance. A cylinder representing a 12" socket extension was placed in the center of the torus.

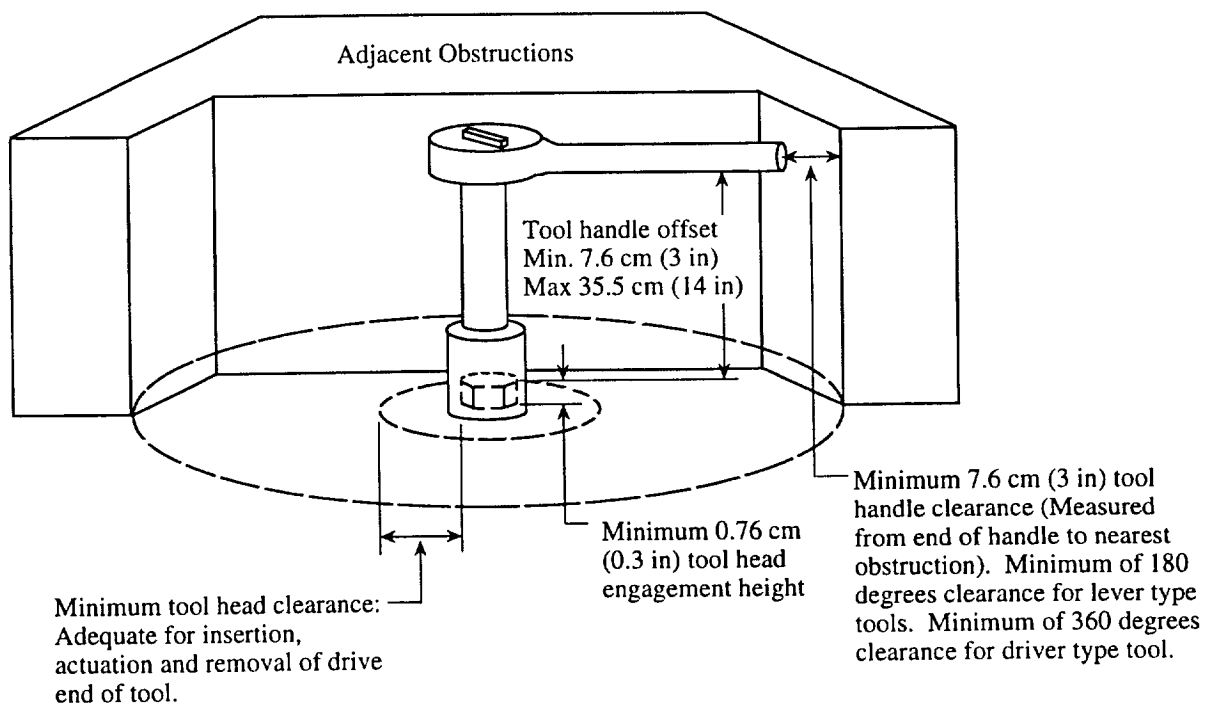


Figure 4.2.3-1 Tool Clearance Envelope from NASA-STD-3000

4.3 CARGO REMOVAL ENVELOPES:

Three cargo items will be unstowed and removed from the STS Cargo Bay and/or SLP envelope: The LCA, the UHF Antenna Assembly, and the PDGF Rigid Umbilical. For the purpose of this analysis, the envelope of the STS Cargo Bay/SLP was considered the 90 inch radius ("r.) of the Orbiter Cargo Bay dynamic envelope. To make this more discernible, the 90"r. cylinder was coupled with a 94"r. cylinder representing the Orbiter Cargo Bay static envelope.

Deployment operations of the SSRMS as concerns this analysis consisted of removal and stowage of the eight tie-down bolts, unfolding and locking the SSRMS booms, securing the Expandable Diameter Fasteners, releasing the FSEGF Hook-Links, and rotation of the unfolded SSRMS booms to the near vertical position (80° - 90°). Actual stepping off of the SSRMS to the ISS Lab Module is a robotic activity and will be performed with crew members working IVA only. The stepping off activity is under the purview of the CSA.

5.0 RESULTS

5.1 TRANSLATION PATHS

The following is the result of the analysis of the LDA Translation Paths:

5.1.1 Longitudinal:

Figure 5.1.1-1 illustrates the required 43 inch diameter clearance corridor along the two longitudinal translation paths. These paths utilize the SLP sill handrails and handholds and are considered nominal. While in the Orbiter Cargo Bay, additional handrails are available along the sill near the hinges of the Orbiter Cargo Bay doors.

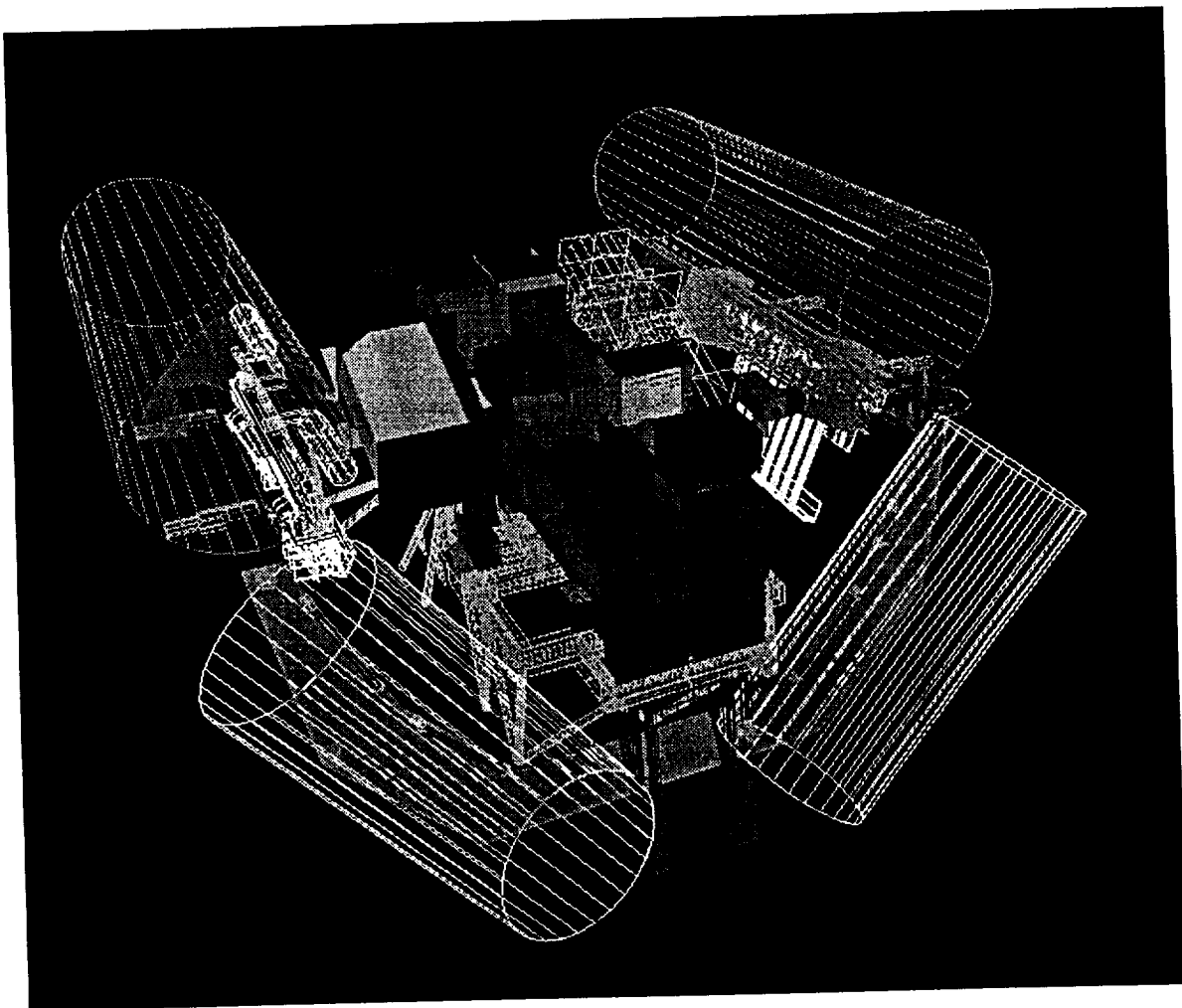


Figure 5.1.1-1 Longitudinal and Port-Starboard Translation Paths for the LDA (View Forward Looking AFT).

5.1.2 Port-Starboard:

Figure 5.1.1-1 illustrates the forward Port-Starboard translation path, and Figure 5.1.2-1 illustrates the aft Port-Starboard translation path. The forward and aft translation paths utilize the handrails located along the interior edge of the SLP frames one and four. The central horizontal section both forward and aft of the SLP have structures (the LCA mounting structure and the MTSAS-P and adapter structure respectively) which provide ample handholds of opportunity for translation. No obvious obstructions were observed other than the FRGF (Port-forward corner of the SLP) which provided a good handhold for turning the corner and also ingressing the APFR when located at position F4 (see Figure 4.2-4). An alternative path would be around the SLP via the standard SLP handrails. The translation paths are not affected by CE removal.

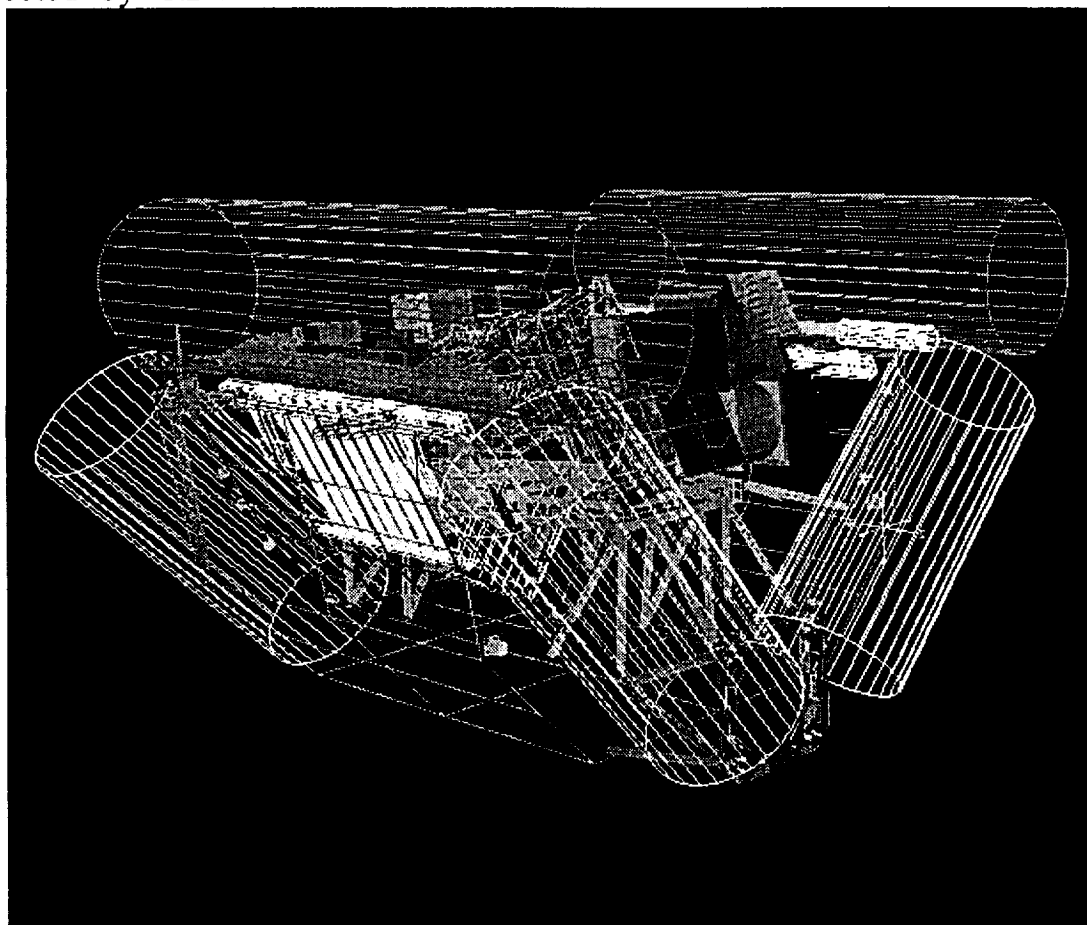


Figure 5.1.2-1 Port-Starboard Translation Paths for the LDA
(View AFT Looking Forward).

5.2 WORK ENVELOPES:

The following results were obtained from the Jack software for reach and clearance envelopes:

5.2.1 Reach Envelope:

Table 5.2-1 Illustrates the calculated reach from the center of the APFR boot plate to the target of the EVA activity. Three EVA tasks exceeded the target range: Removal of Tie-down bolts from SSRMS light end, tighten lower EDFs from SSRMS Port side, Removal of Tie-down bolts from SSRMS heavy end (Port), and manipulate SSRMS clutches. In that case, the worksite was only a short distance from the target range and didn't take into account the ability of the Astronaut to reorient the APFR to a more suitable setting or to use a shorter extension (other than 12") on an Essex wrench. In the case of removal of the Tie-down bolts from SSRMS heavy end, the distance to the worksite was exacerbated by the convention used for orienting the APFR. In actuality, the APFR would have been rolled left, which would bring the APFR bootplate closer to the worksite. In any case this task will probably require a right angle extension on the power tool. The manipulation of SSRMS clutches is considered a single handed task and would likely be performed in free float.

The configuration used for each of the measurements is illustrated in Figures 5.2-1 through 5.2-26.

Table 5.2-1 Calculated distance for the center of the APFR to the worksite listed by EVA task. Also listed are the suggested handrail or handhold locations for ingress of the APFR and the orientation of the APFR in the WIF.

TASK	FR#	Position*	File No.	Hand Rail	HR-HH within 48"	APFR ORIENT. in WIF	Pitch	Distance from APFR to worksite	Within Two-Handed (2H) Reach?
Loosen Forward Bolt From Rigid Umbilical Assembly	F4	RU1	F4-RU1	FRGF brace	YES	12:00 O'clock 0°	-18°	134.1cm (52.8")	YES
Loosen AFT EVA Bolt From Rigid Umbilical Assembly	A2	RU2	A2-RU2	Pallet H.R.	YES	1:00 O'clock 30°	-18°	160.25cm (63.1")	YES
Loosen Center Bolt From Rigid Umbilical Assembly	A1	RU3	A2-RU3	HR on RU	YES	12:00 O'clock 0°	-63°	158.6cm (62.4")	YES
Loosen AFT Retaining Bolts from UHF Antenna Assy.	A3	UH1	A3-UH1	Pallet H.R.	YES	12:00 O'clock 0°	-9°	137.4cm (54.1")	YES
Loosen Forward Bolts from UHF Antenna Assy.	F2	UH2	F2-UH2	Upper SBD.	YES	12:00 O'clock 0°	0°	149.7cm (58.9")	YES
Loosen Center EVA Bolts from UHF Antenna Assy.	F1	UH3	F1-UH3	Pallet H.R.	YES	11:00 O'clock 30°	-45°	149.8cm (59.0")	YES
Remove Tie-down Bolts from SSRMS Light End	F3	SB1	F3-SB1	M.F.-SSRMS	YES	12:00 O'clock 0°	0°	151.2cm (59.5")	YES
Tighten Lower EDFs SSRMS Light End - Port Side	F3	ED1	F3-ED1	M.F.-SSRMS	YES	12:00 O'clock 0°	0°	161.5cm (63.6")	Out of 2 H reach **
Tighten Lower EDFs SSRMS Light End - Starboard	F3	ED2	F3-ED2	M.F.-SSRMS	YES	12:00 O'clock 0°	0°	149.2cm (58.7")	YES
Release Hook-Link top EVA bolt on FSEGF Port Upper	F5	HL1	F5-HL1	HR on LSA	YES	1:00 O'clock 30°	18°	131.7cm (51.9")	YES
Release Hook-Link top EVA bolt on FSEGF Port Inner	F5	HL2	F5-HL2	HR on LSA	YES	1:00 O'clock 30°	18°	141.6cm (55.7")	YES

*Position refers to the position of the APFR as used in the LDA Neutral Buoyancy Tests and designates the task number as well as orientation of the APFR.

** Out of Ideal Range (Two-Handed Reach) of 125.5cm.<Range<164.0cm. (49.4"<Range<64.6").but within one-handed reach (44.7"<reach<72.3")

Table 5.2-1 Continued

TASK	FR#	Position*	File No.	Hand Rail	HR-HH within 48"	APFR ORIENT. in WIF	Pitch	Distance from APFR to worksite	Within Two-Handed (2H) Reach?
SSRMS Clutch manipulation	A1	N/A	A1-SSRMS-C	micro-SSRMS	YES	3:00 O'Clock 90°	0°	167.9cm (66.1")	Out of 2 H reach **
Remove Tie-down Bolts from SSRMS Heavy End (Port).***	A1	SB2	A1-SB2	micro-SSRMS	YES	3:00 O'Clock 90°	0°	194.6cm (76.6")	Out of 1 H reach by 4.3"
Remove Tie-down Bolts from SSRMS Heavy End (Starboard). ***	A4	SB3	A4-SB3	micro-SSRMS	YES	10:00 O'Clock 300°	0°	194.6cm (76.6")	Out of 1 H reach by 4.3"
Slide EVA Knob on Bolt Container- center EVA bolt	A1	BC2	A1-BC2	Pallet HR	YES	12:00 O'Clock 0°	-63°	156.7cm (61.7")	YES
Secure Center EVA bolt on Bolt Container	A1	BC3	A1-BC2	Pallet HR	YES	12:00 O'Clock 0°	-63°	156.7cm (61.7")	YES
Secure Aft EVA bolt on Bolt Container	A1	BC1	A1-BC1	Pallet HR	YES	12:00 O'Clock 0°	-63°	110.7cm (43.6")	YES
Secure Fwd EVA bolt on Bolt Container	F4	BC4	F4-BC4	Pallet HR	YES	12:00 O'Clock 0°	-63°	168.5cm (66.3")	Out of 2 H reach **
Remove EVA bolt securing LCA- Starboard	F2	LC1	F2-LC1	For'd HR	YES	7:00 O'Clock 210°	+90°	160.4cm (63.2")	YES
Remove EVA bolt securing LCA- Top	F3	LC2	F3-LC2	For'd HR	YES	9:00 O'Clock 270°	+30°	156.6cm (61.6")	YES
Secure Strut for LCA after Removal OF LCA	F2	LC4	F2-LC4	For'd HR	YES	3:00 O'clock 90°	+15°	169.7cm (66.8")	Out of 2 H reach **
Mating Lab Connector J300	A2	LM1	A2-J300	Aft. HR	YES	5:00 O'clock 150°	+15°	165.9cm (65.3")	Out of 2 H reach **

** Out of Ideal Range (Two-Handed Reach) of 125.5cm.<Range<164.0cm. (49.4"<Range<64.6"),but within one-handed reach (44.7"<reach<72.3").

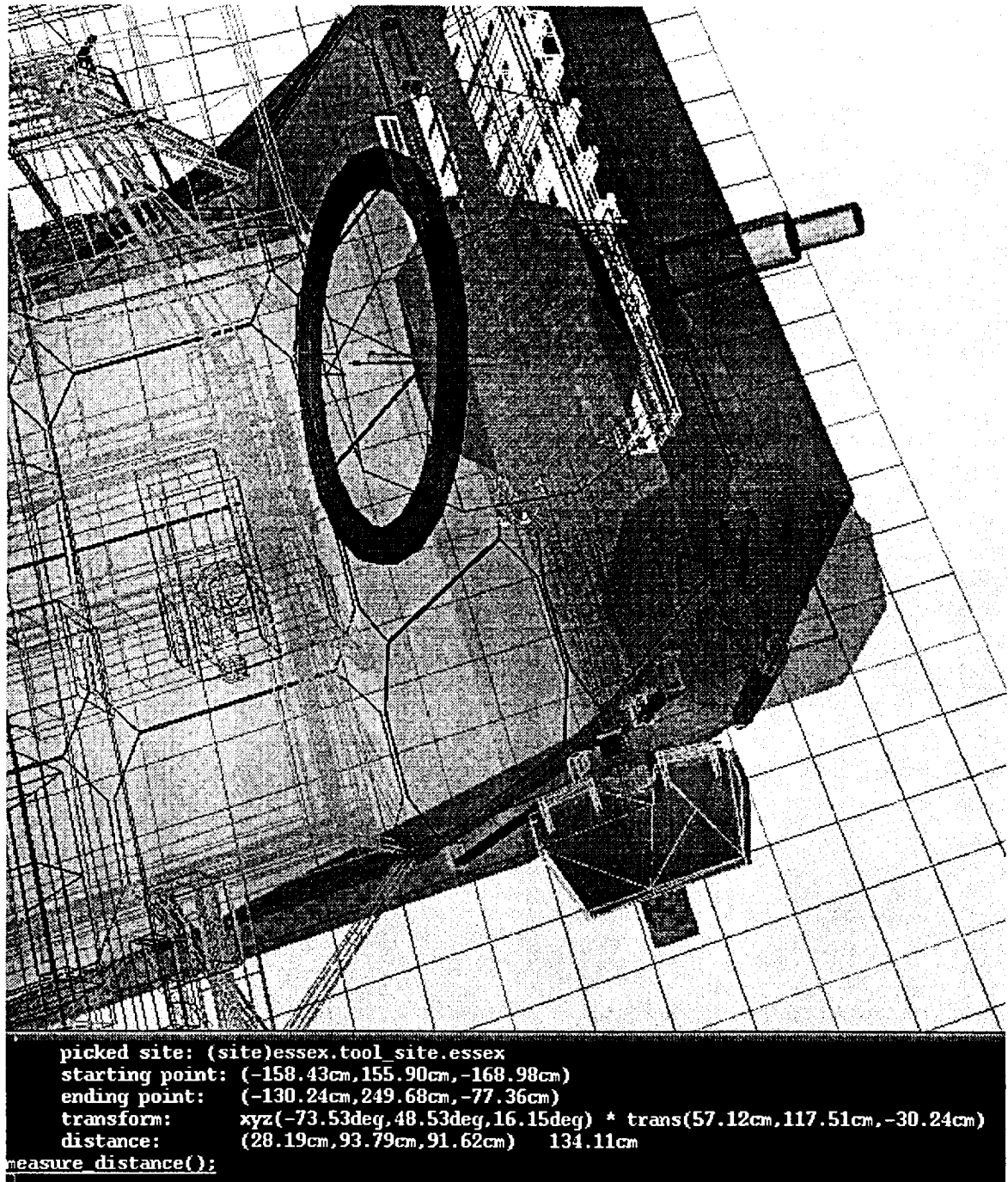
*** Mirror Image (Port-Starboard)

This task will be performed by crew member in PFR on the SRMS.

Table 5.2-1 Continued

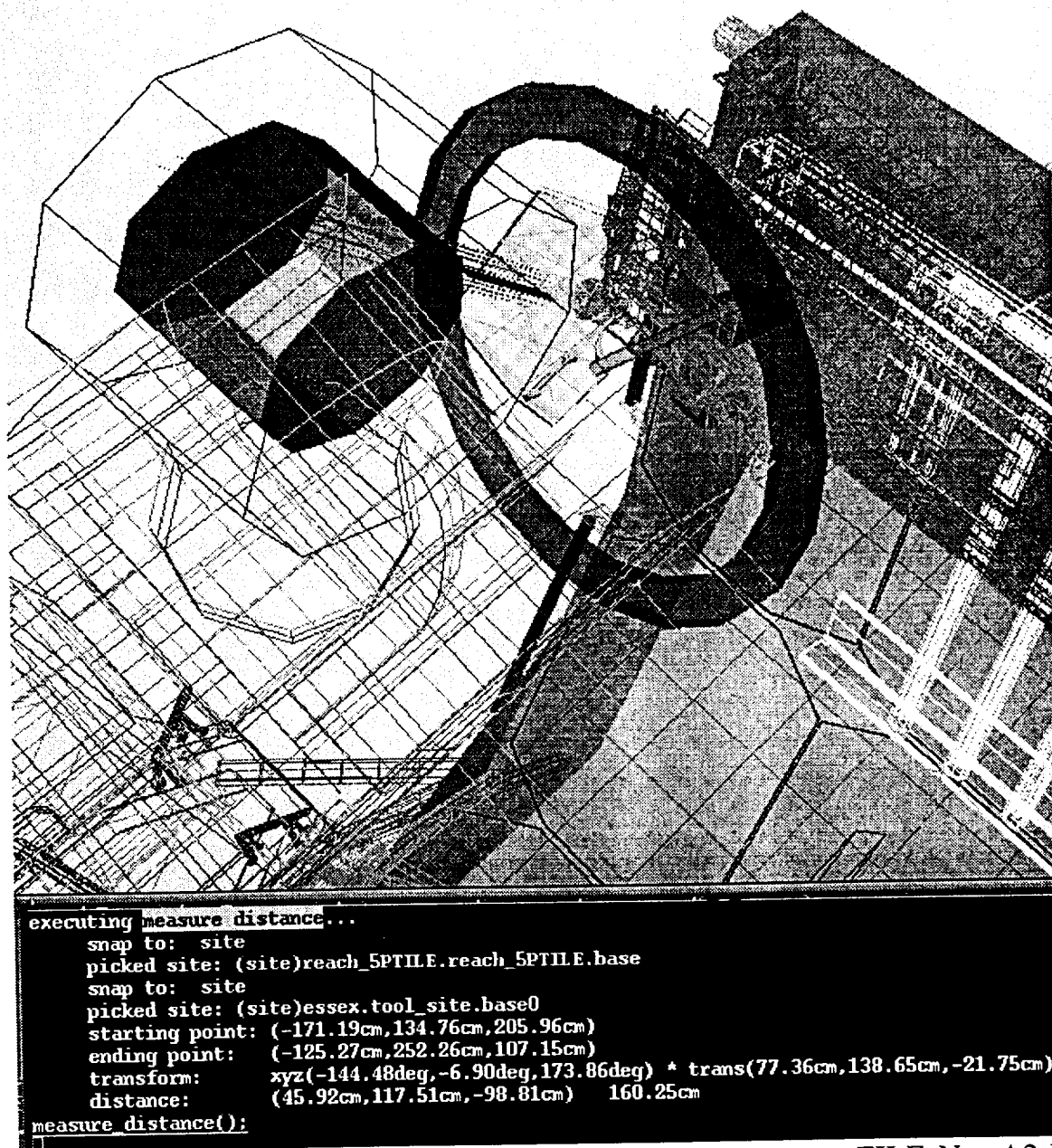
TASK	FR#	Position*	File No.	Hand Rail	HR-HH within 48"	APFR ORIENT. in WIF	Pitch	Distance from APFR to worksite	Within Two-Handed (2H) Reach?
Mating Lab Connector J304	A 2	LM4	A 2 - J304	Aft. HR	YES	3:00 O'clock 90°	+15°	139.4cm (54.9")	YES
Accessing Dummy Connector Panel	A 1	DC1	A 1 - DC1	Aft. HR	YES	4:00 O'clock 120°	+15°	179.8cm (70.8")	Out of 2 H reach **
Release Forward FRGF EVA Interface Bolt	F 5	FRG1	F 5 - FRG1	Strut on FRGF	YES	3:00 O'Clock 90°	30°	181.8cm (71.6")	Out of 2 H reach **
Release Aft FRGF EVA Interface Bolt	F 5	FRG2	F 5 - FRG2	Strut on FRGF	YES	3:00 O'Clock 90°	30°	172.5cm (67.9")	Out of 2 H reach **

** Out of Ideal Range (Two-Handed Reach) of 125.5cm.<Range<164.0cm. (49.4"<Range<64.6"),but within one-handed reach (44.7"<reach<72.3").



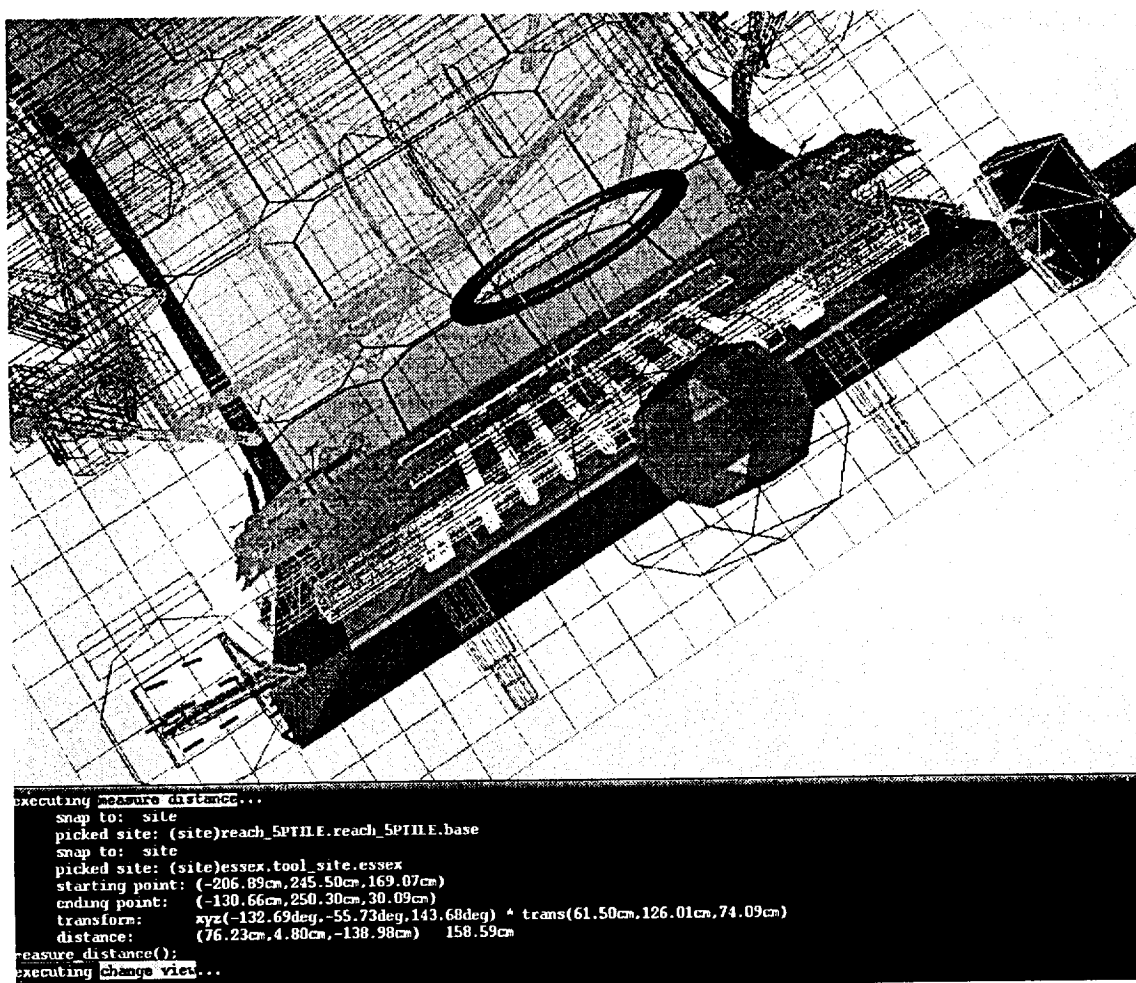
FILE No. F4-RU1

Figure 5.2.1-1 Loosening the Forward EVA Bolt (RU1) from the PDGF Rigid Umbilical from position F4.



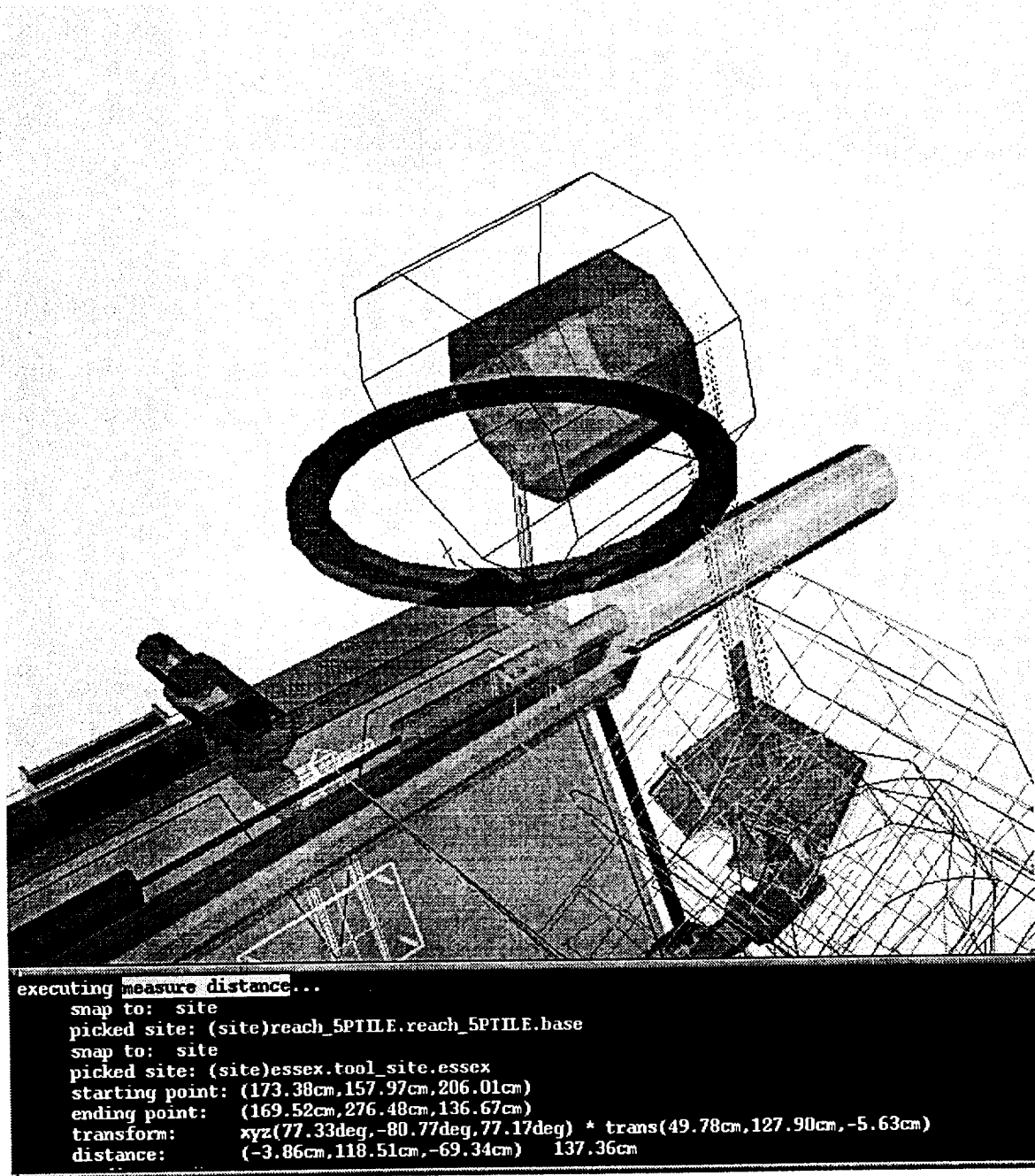
FILE No. A2-RU2

Figure 5.2.1-2 Loosening the AFT EVA Bolt (RU2) from the PDGF Rigid Umbilical from position A2.



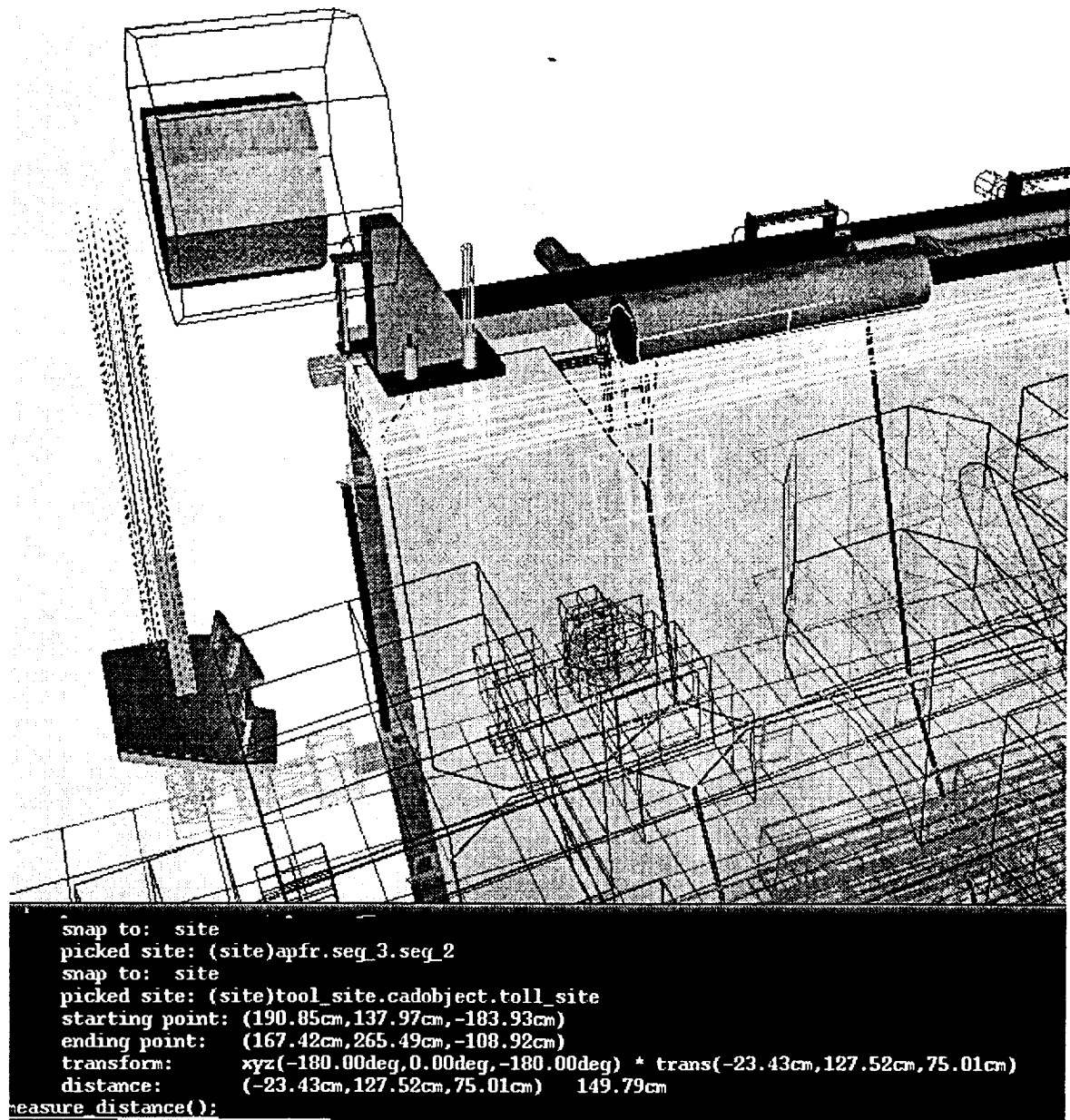
FILE No. A2-RU3

Figure 5.2.1-3 Loosening the Center EVA Bolt (RU3) from the PDGF Rigid Umbilical from position A1.



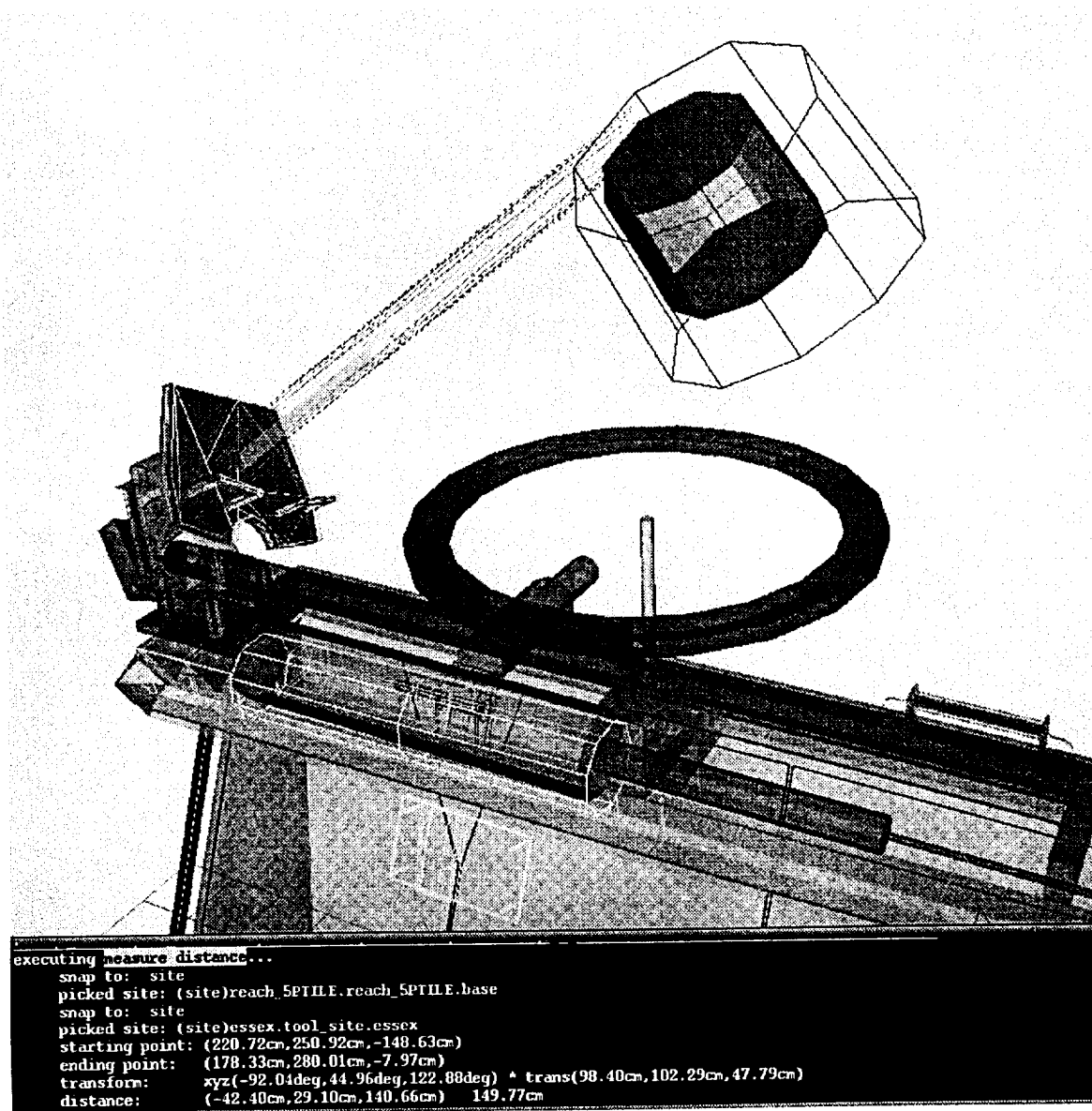
FILE No. A3-UH1

Figure 5.2.1-4 Loosening the Aft EVA Bolt (UH1) from the UHF Antenna Assembly from position A3.



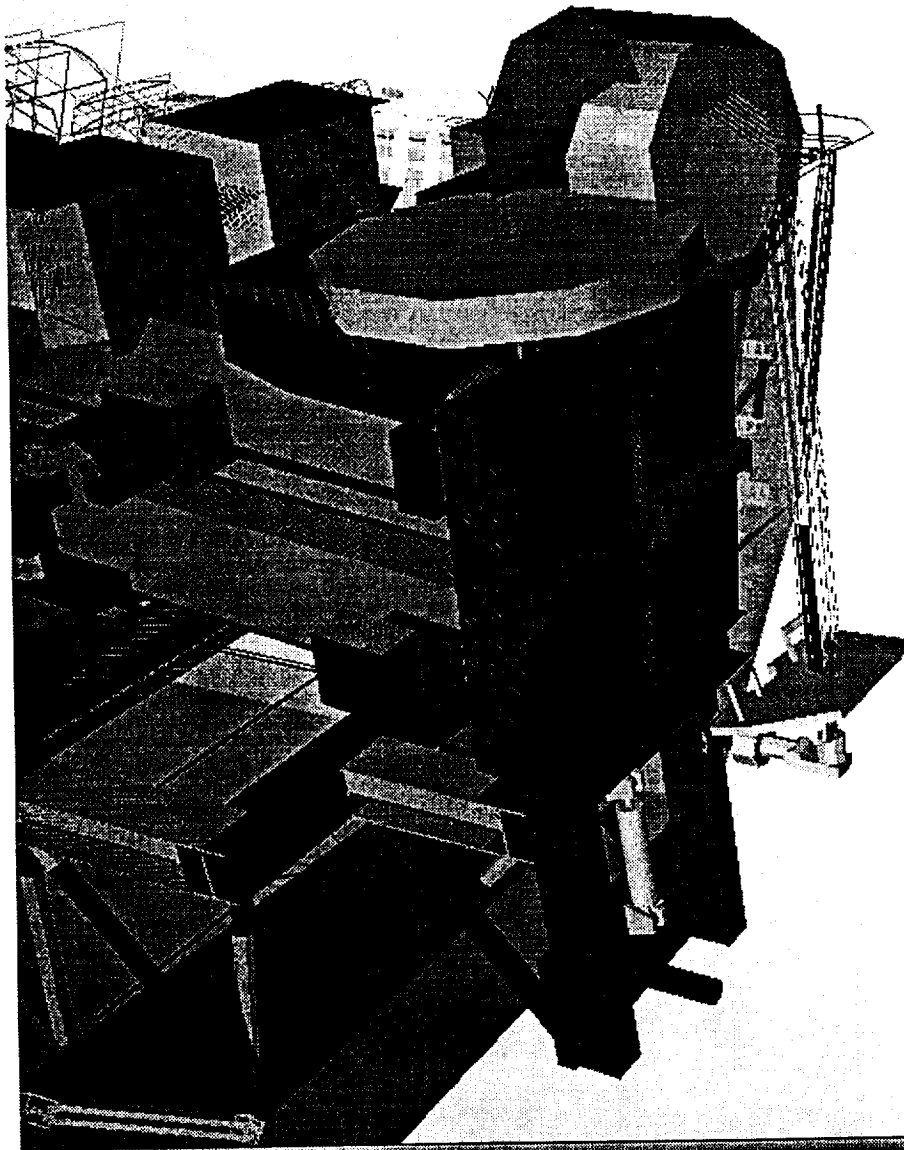
FILE No. F2-UH2

Figure 5.2.1-5 Loosening a Forward EVA Bolt (UH2) from the UHF Antenna Assembly from position F2.



FILE No. F1-UH3

Figure 5.2.1-6 Loosening a Center EVA Bolt (UH3) from the UHF Antenna Assembly from position F1.



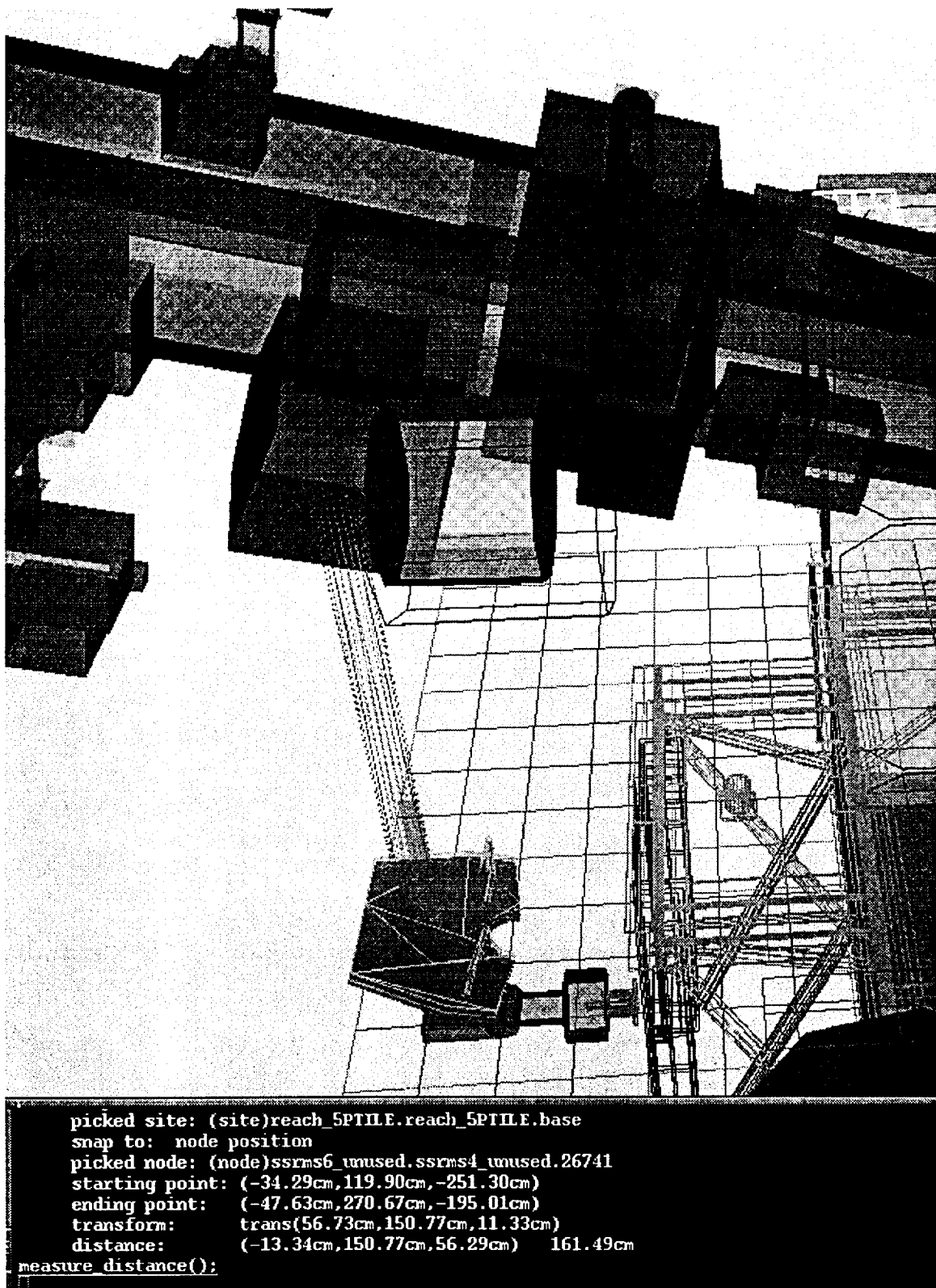
```

executing measure distance...
snap to: site
picked site: (site)apfr.reach_5PTILE.base
snap to: site
picked site: (site)tool_clr.cadobject.tool_reach
starting point: (-31.00cm,134.55cm,-234.62cm)
ending point: (21.60cm,271.60cm,-198.45cm)
transform: xyz(180.00deg,87.96deg,-180.00deg) * trans(34.27cm,137.05cm,-53.85cm)
distance: (52.60cm,137.05cm,36.17cm) 151.18cm
measure distance():

```

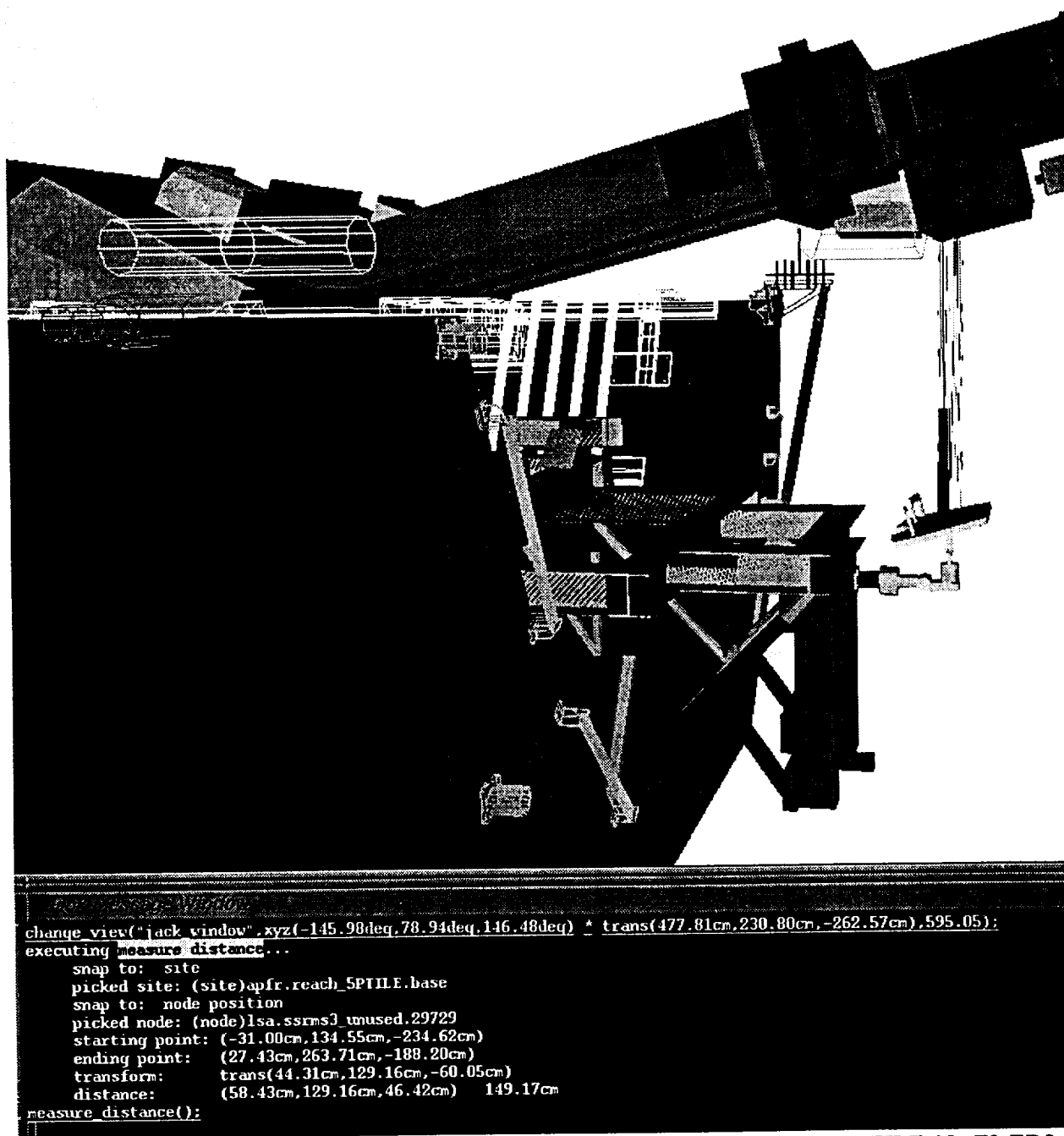
FILE No. F3-SB1

Figure 5.2.1-7 Removing the Tie-down Bolts (SB1) from the SSRMS Light End (Forward) from Position F3.



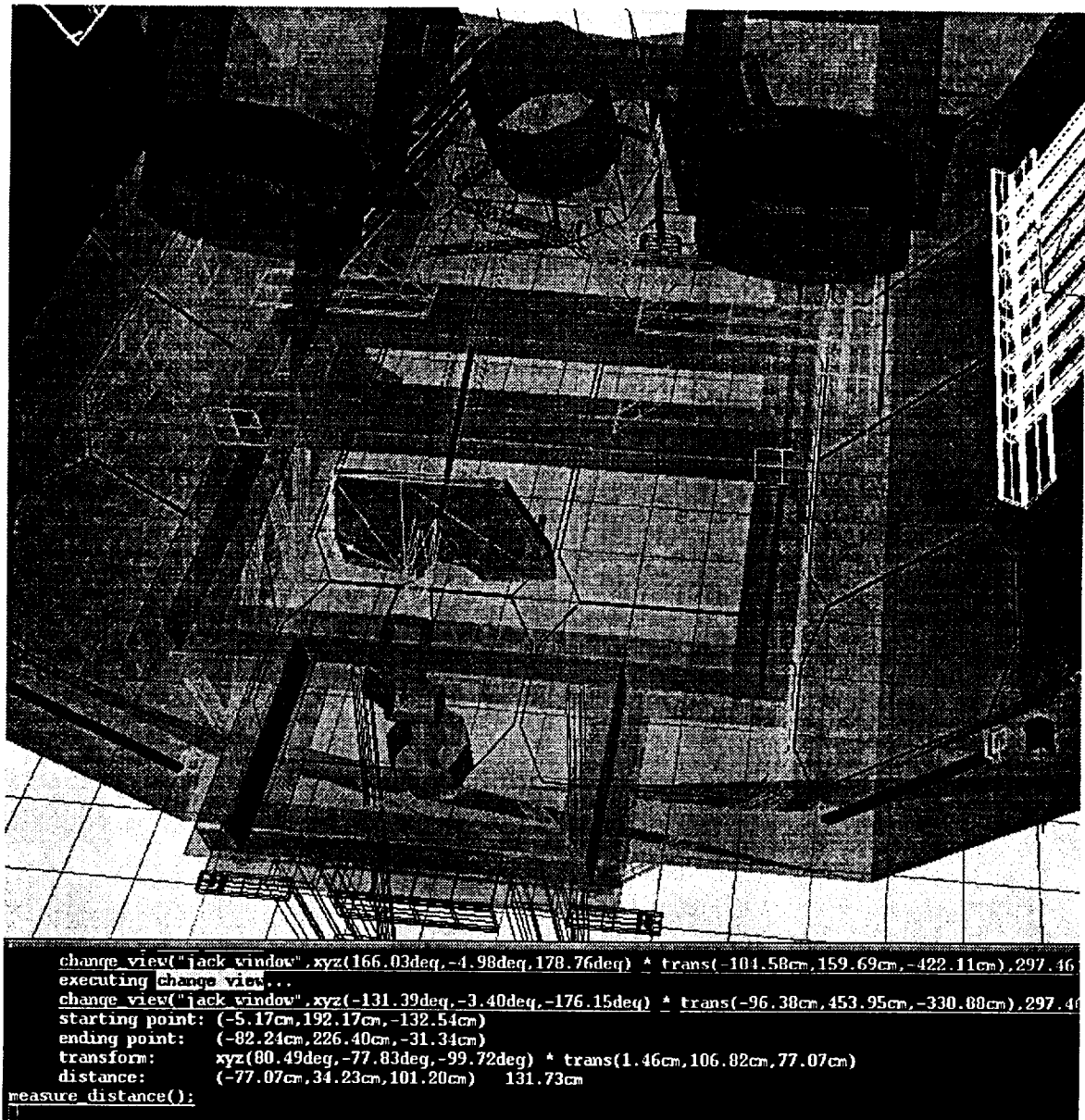
FILE No. F3-ED1

Figure 5.2.1-8 Tightening the Lower EDFs (ED1) on the Port Side from position F3.



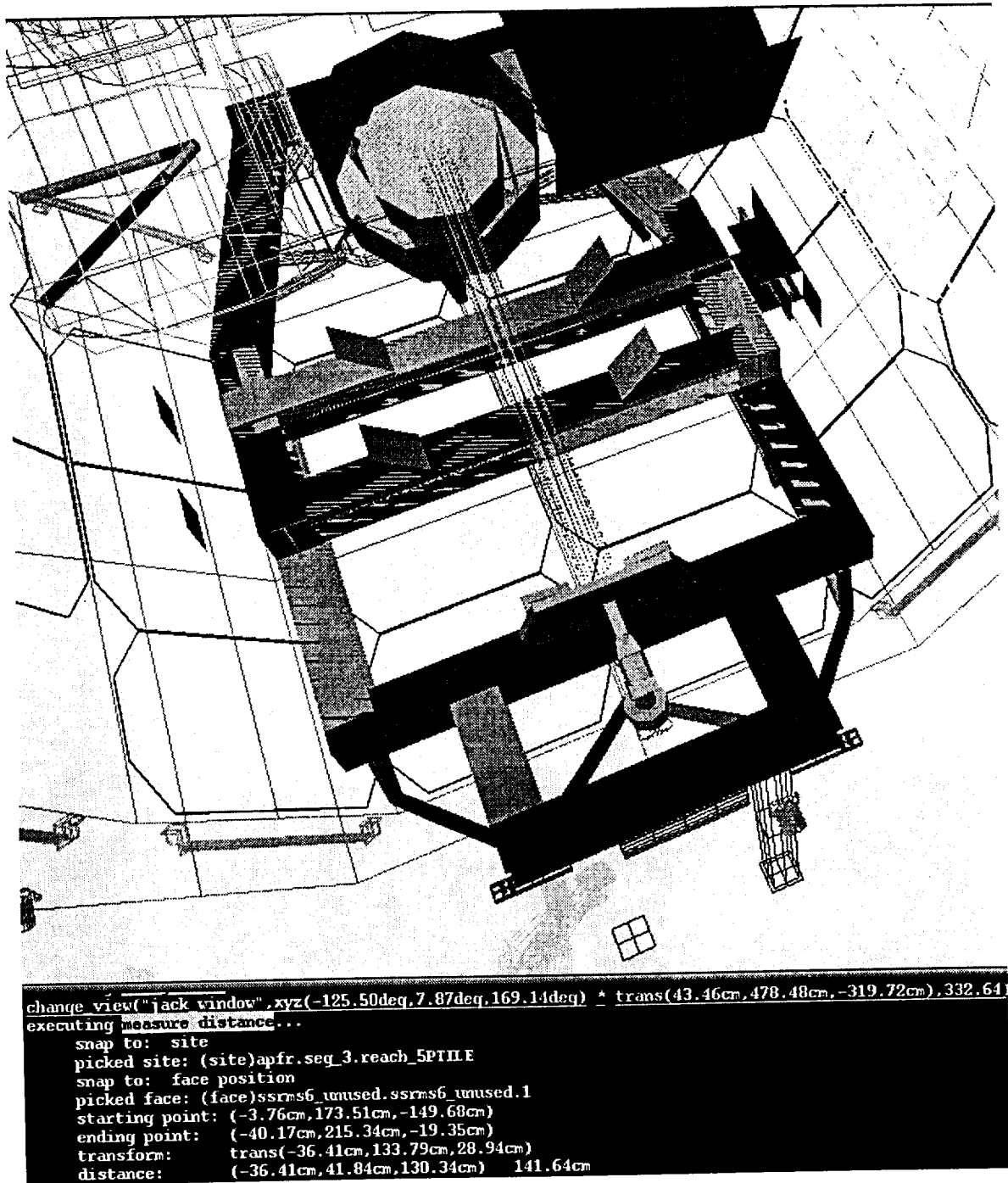
FILE No.F3-ED2-S

Figure 5.2.1-9 Tightening the Lower EDFs (ED2) on the Starboard Side from position F3.



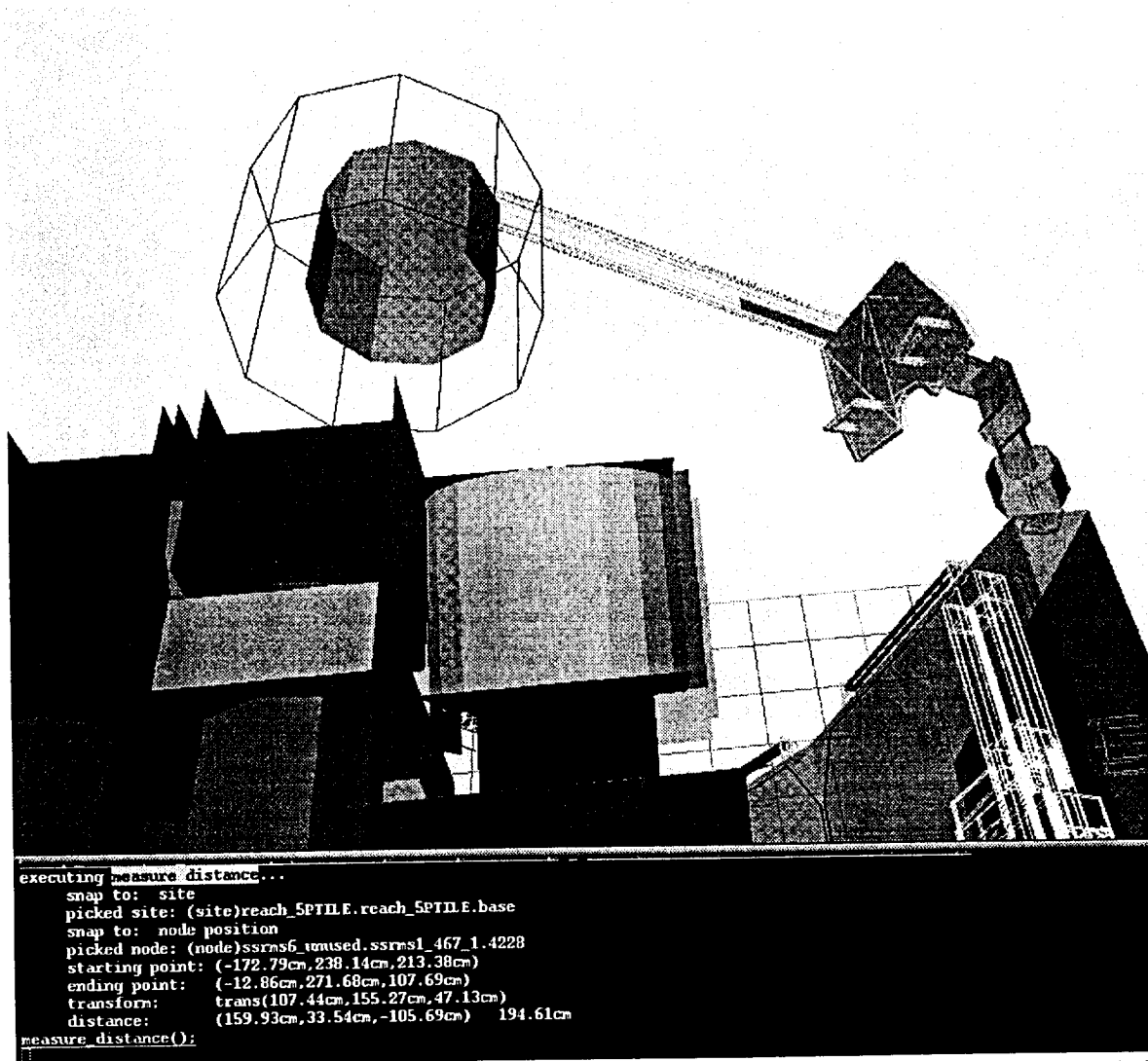
FILE No. F5-HL1

Figure 5.2.1-10 Releasing the Top Hook-Link EVA Bolt (HL1) on the FSEGF from position F5.



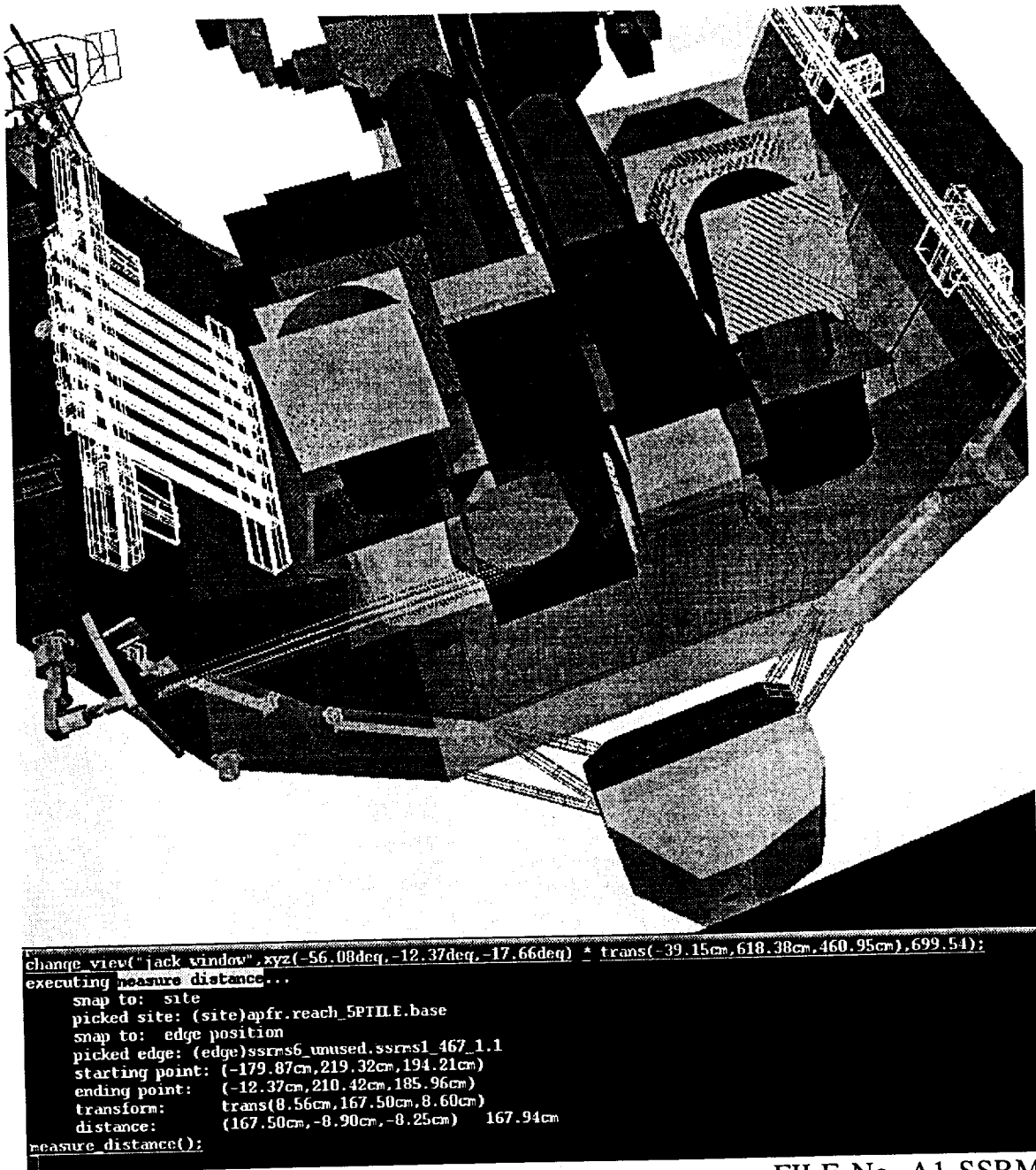
FILE No. F5-HL2

Figure 5.2.1-11 Releasing the Inner Hook-Link EVA Bolt (HL2) on the FSEGF from position F5.



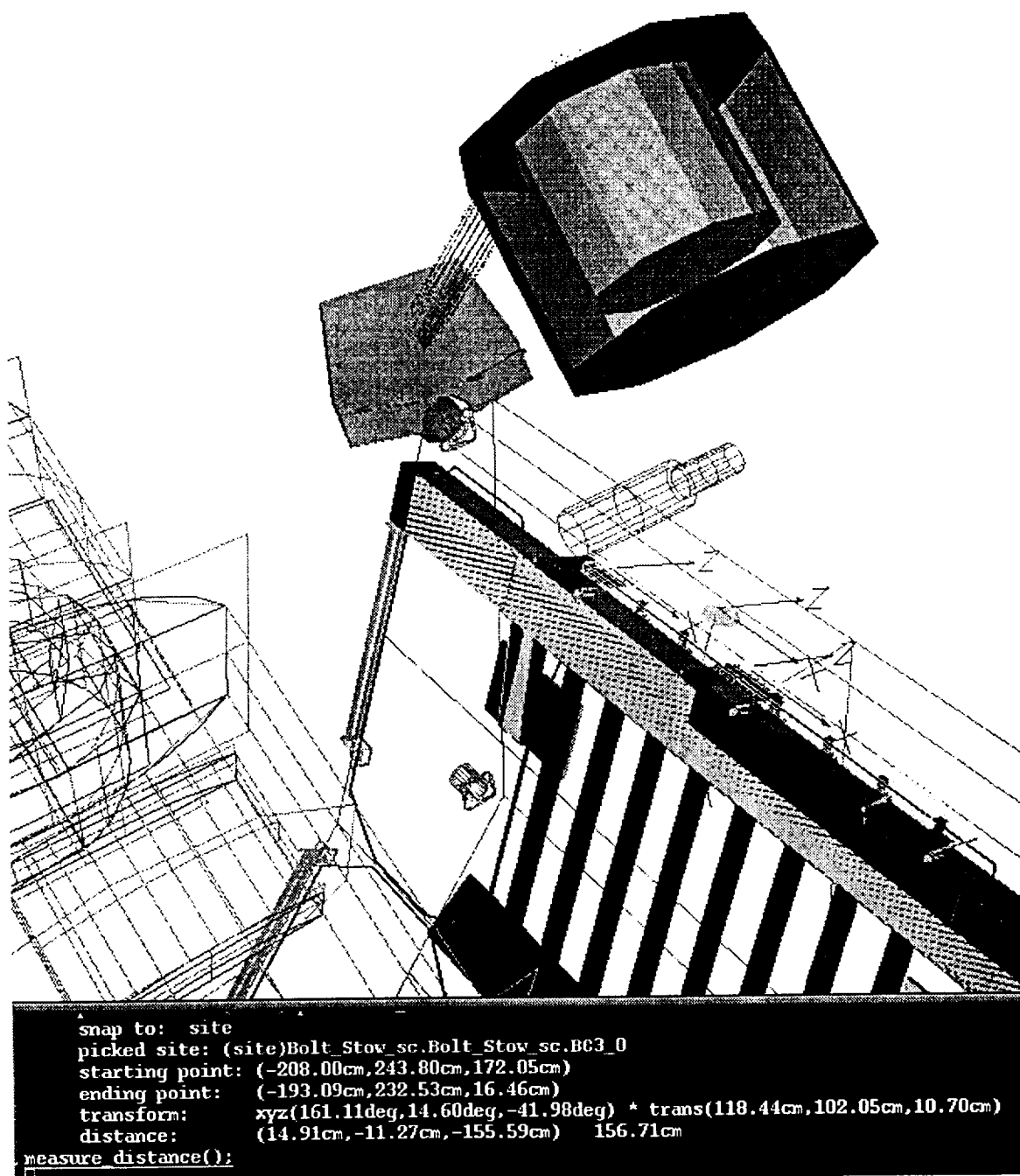
FILE No. A1-SB2

Figure 5.2.1-12 Removing the Tie-down Bolts (SB2) from the SSRMS Heavy End (Aft) from position A1.



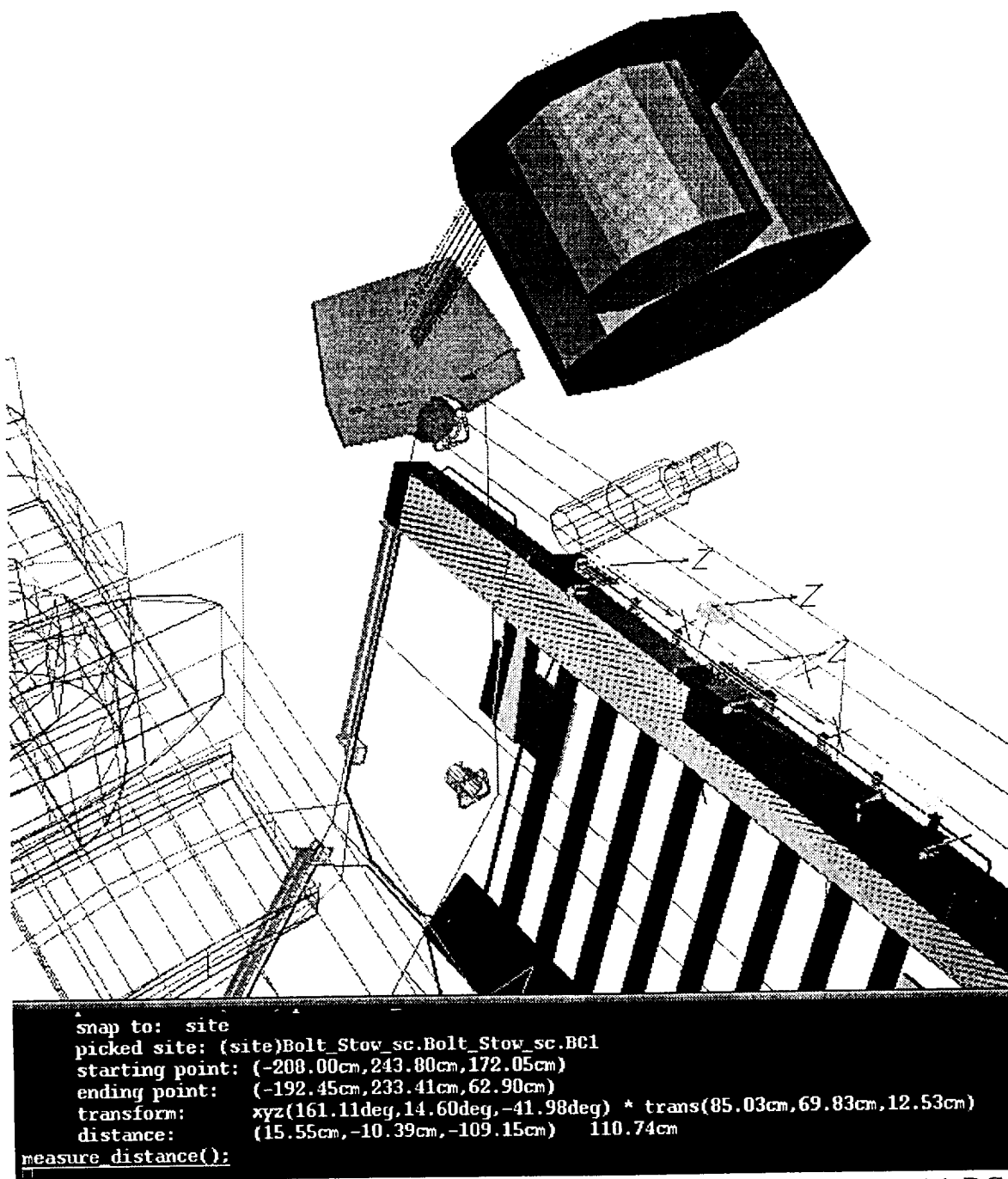
FILE No. A1-SSRMS-C

Figure 5.2.1-13 Manipulating the SSRMS Clutches from position A1.
(This activity is planned to be performed free float)



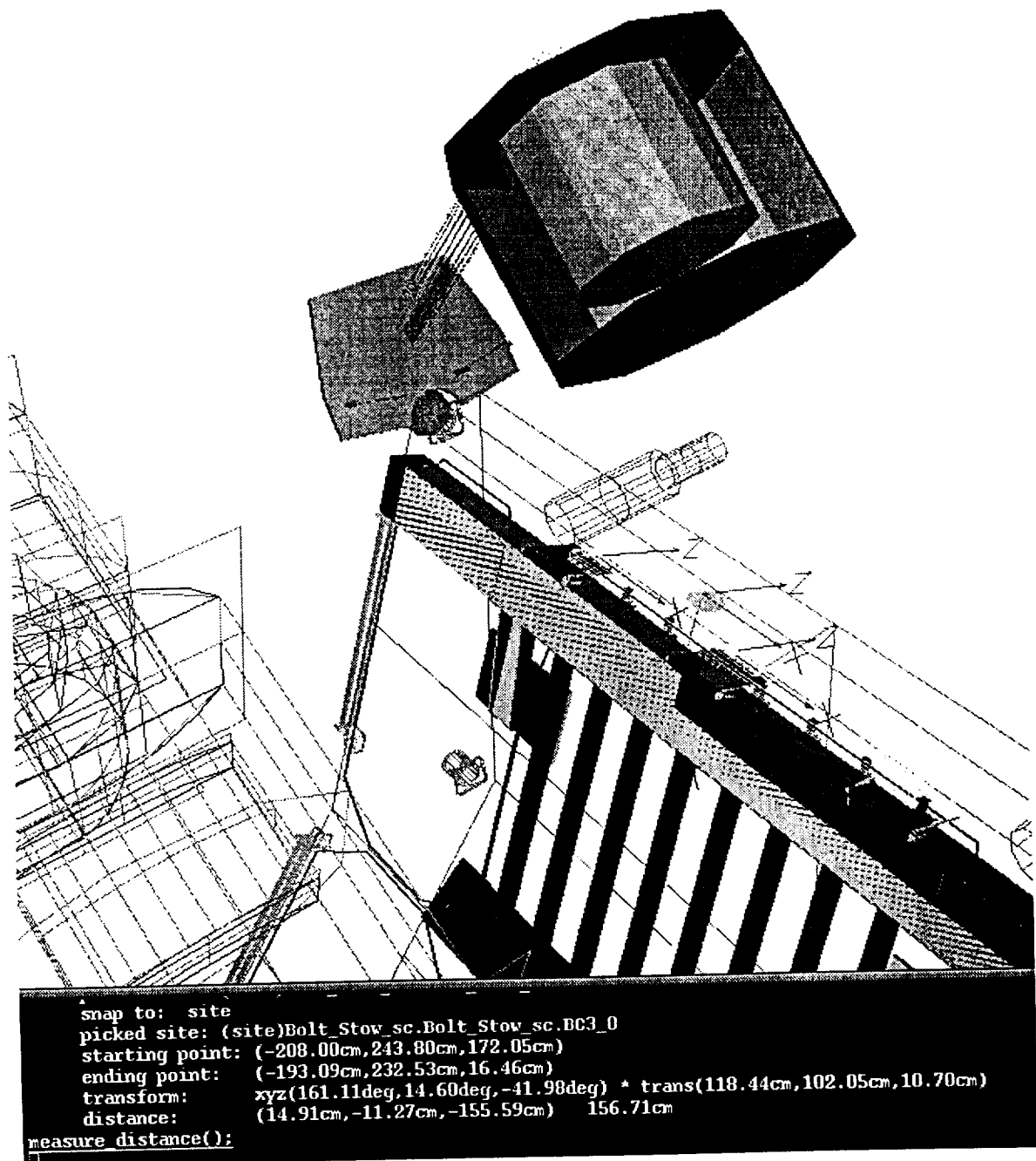
FILE No. A1-BC2

Figure 5.2.1-14 Closing the Tie-down Bolt Stowage Cover (BC2) From position A1.



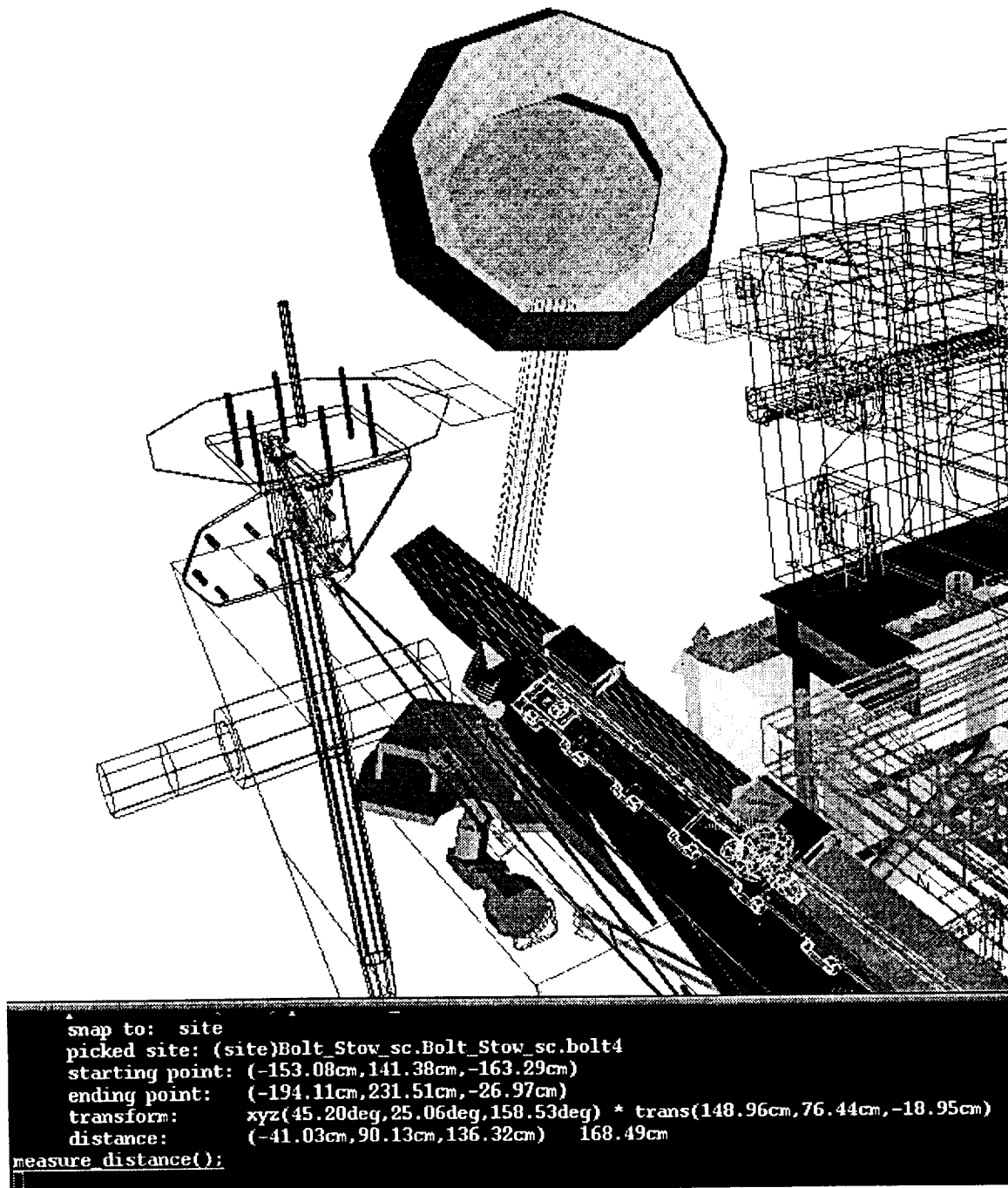
FILE No. A1-BC1

Figure 5.2.1-15 Securing the Aft EVA Bolt (BC1) on the Tie-down Bolt Stowage Cover From position A1.



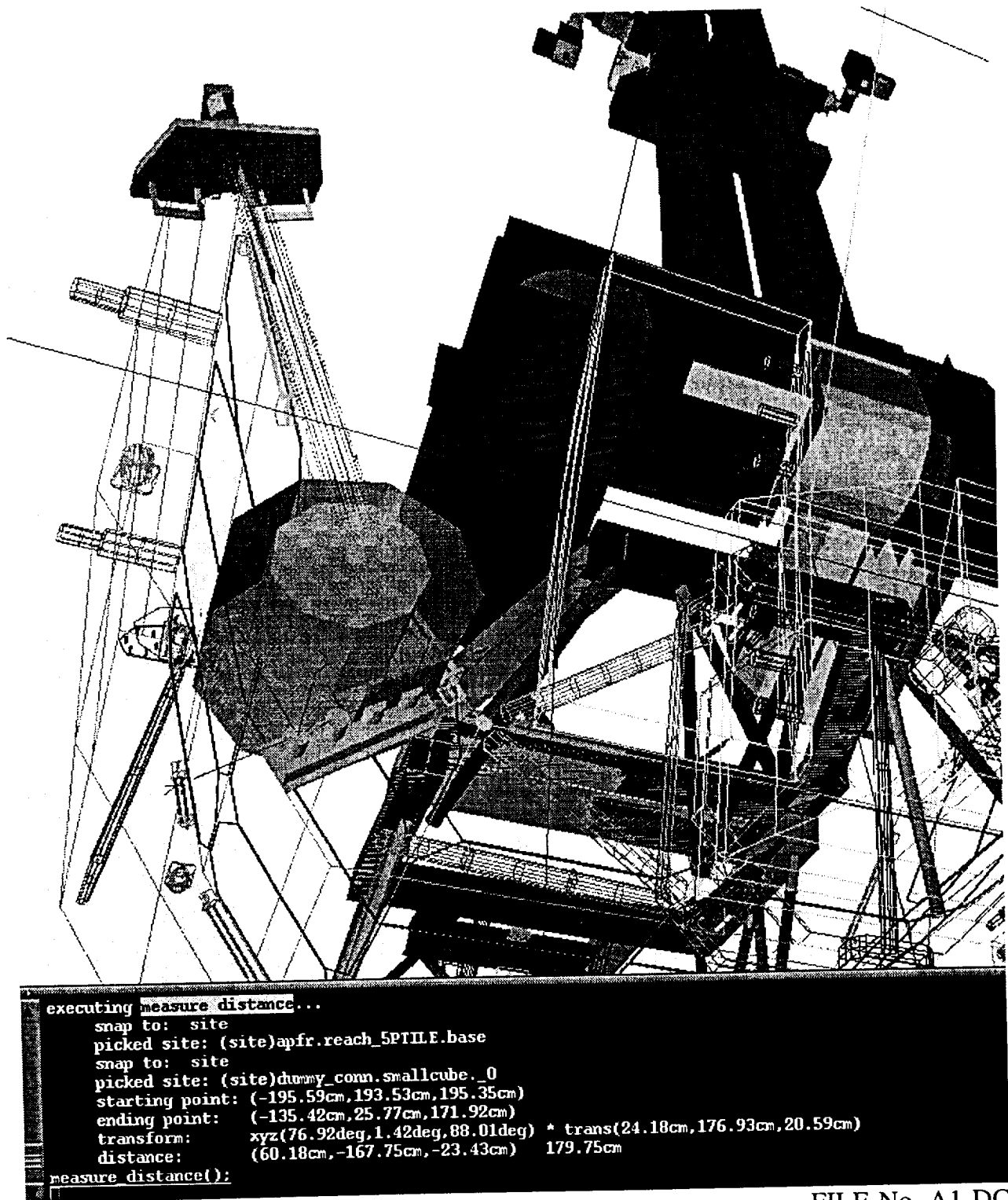
FILE No. A1-BC3

Figure 5.2.1-16 Securing the Center EVA Bolt (BC3) on the Tie-down Bolt Stowage Cover From Position A1.



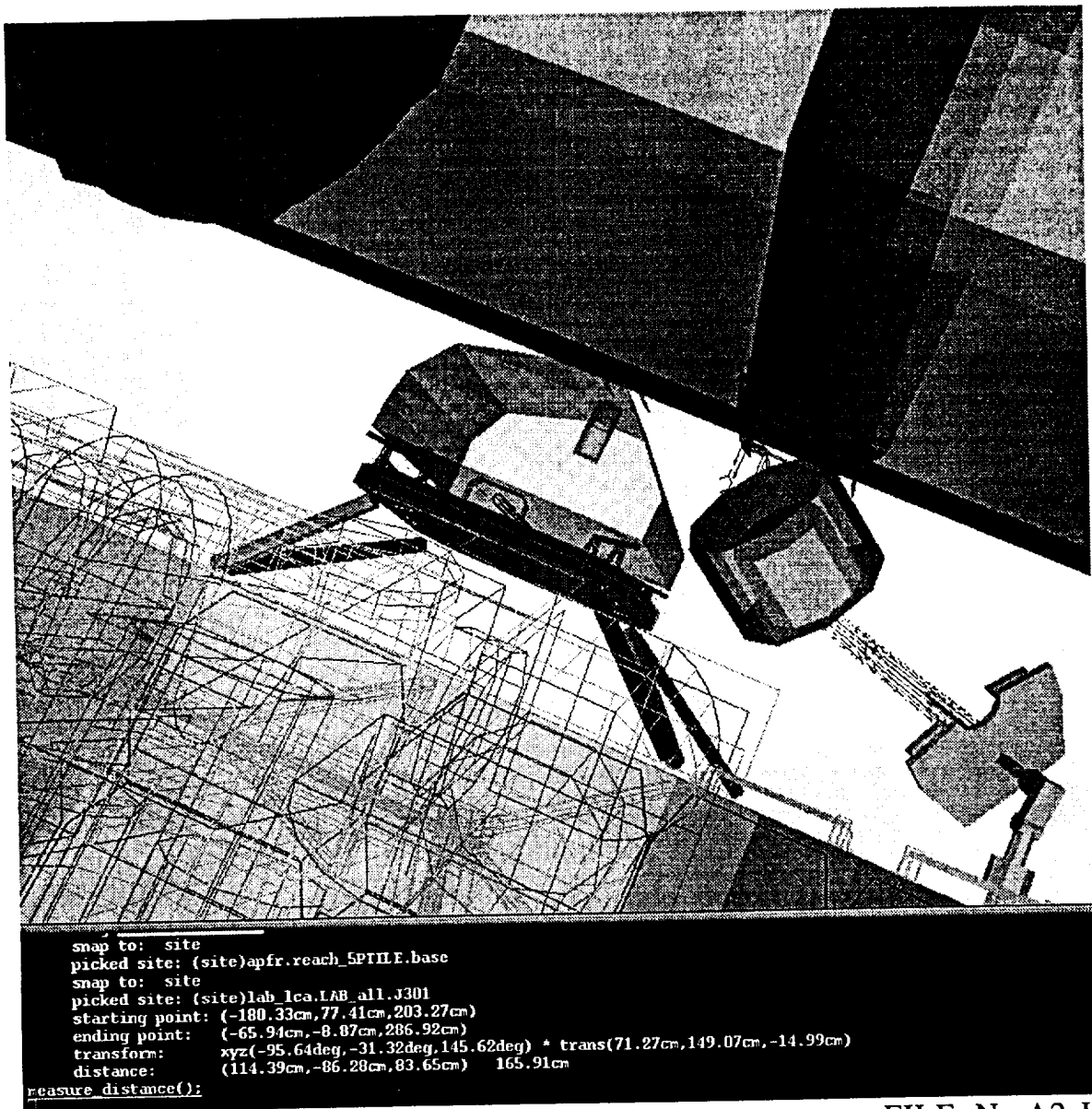
FILE No. F4-BC4

Figure 5.2.1-17 Securing the Forward EVA Bolt (BC4) on the Tie-down Bolt Stowage Cover From Position F4



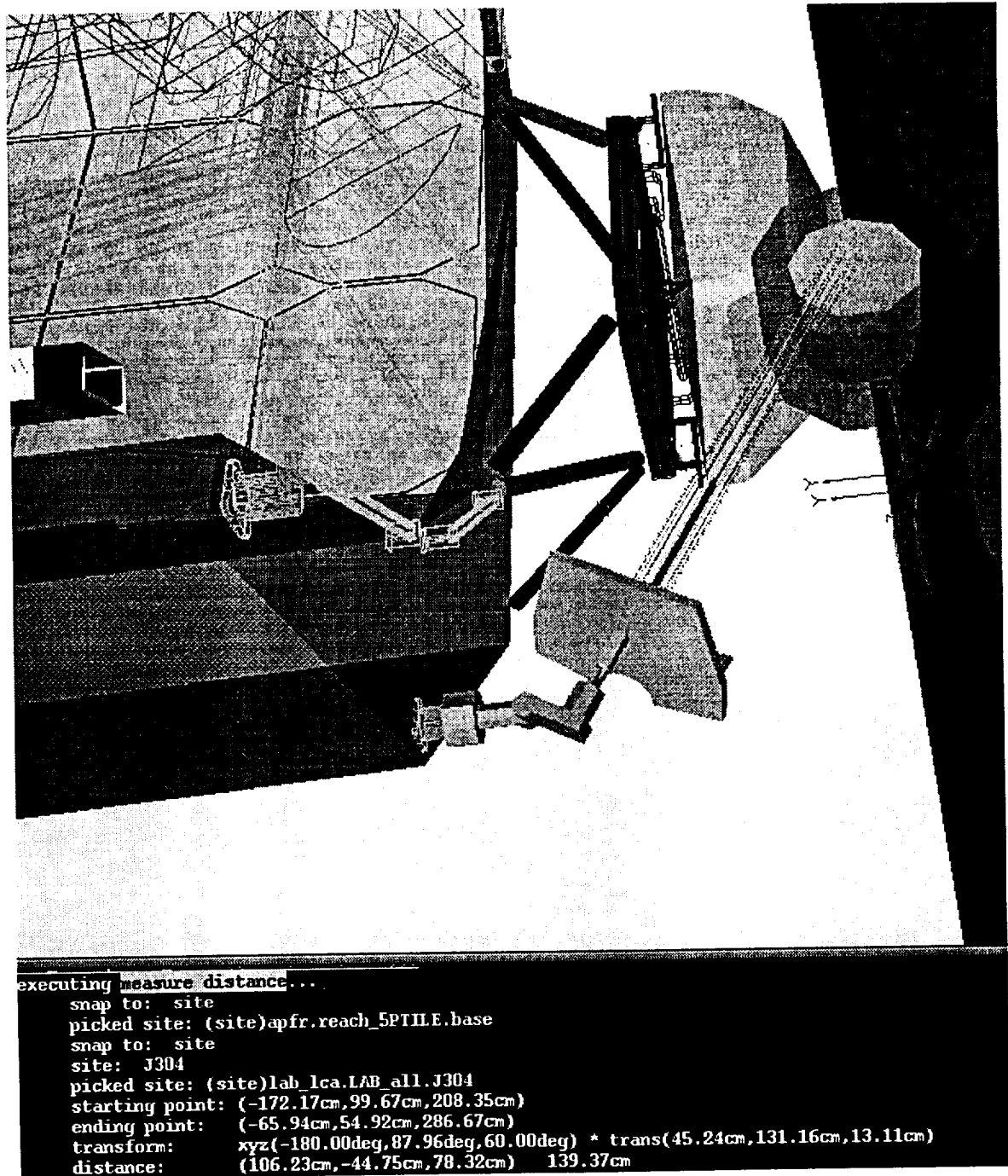
FILE No. A1-DC

Figure 5.2.1-18 Accessing the Dummy Connector Panel (DC1)
from Position A1



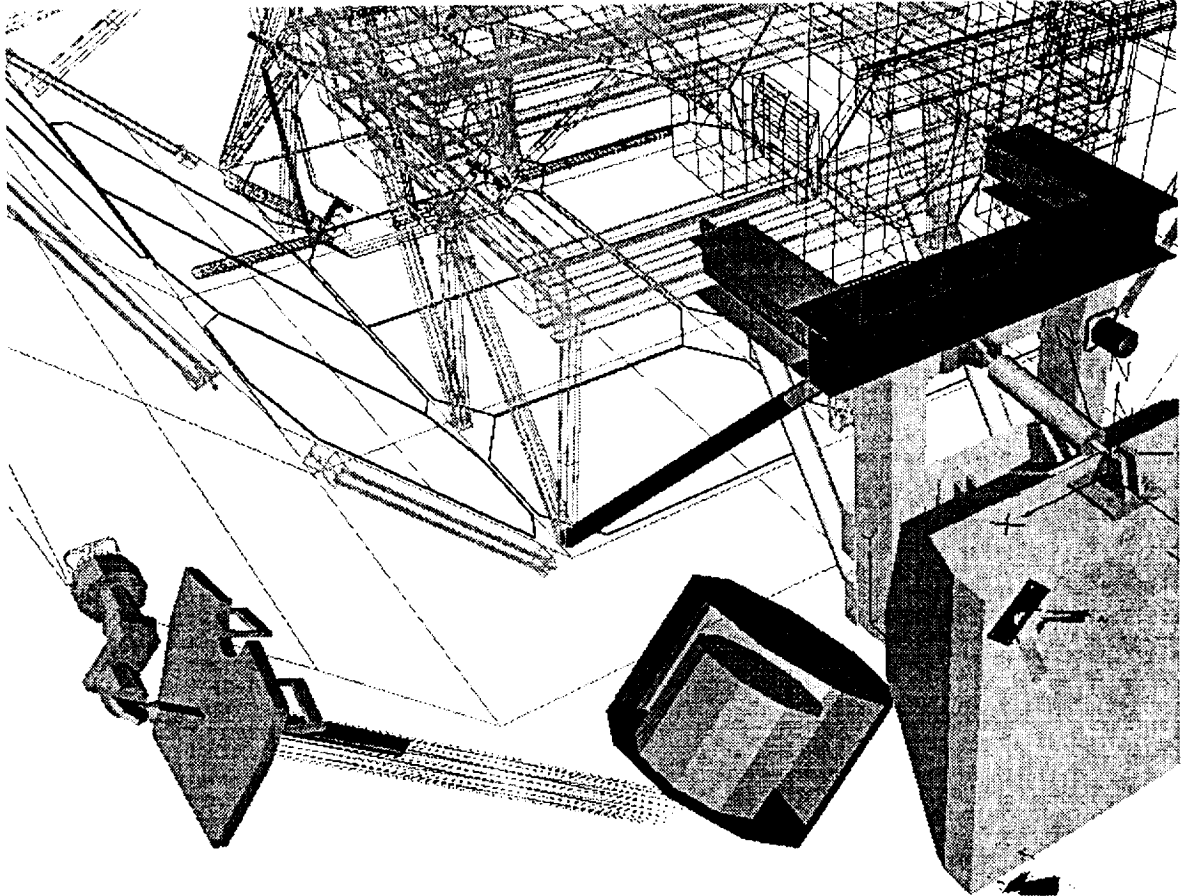
FILE No.A2-J300

Figure 5.2.1-19 Accessing the Lab Connector J300 from Position A2.



FILE No. A2-J304

Figure 5.2.1-20 Accessing the Lab Connector J304 from Position A2.



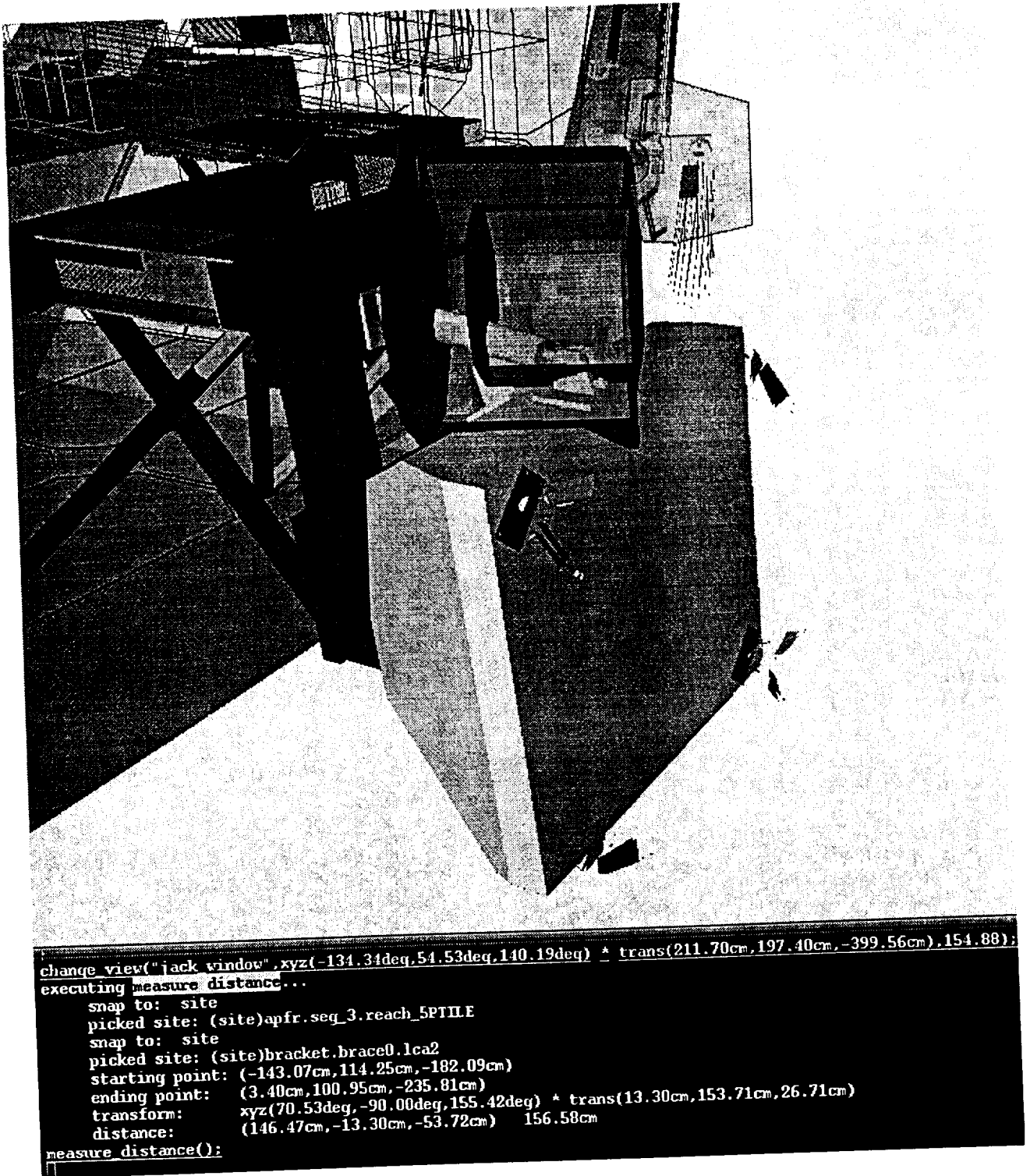
```

snap to: site
picked site: (site)lca fse.smallcube0.lcal
starting point: (186.96cm,83.67cm,-169.77cm)
ending point: (34.33cm,38.47cm,-189.58cm)
transform: xyz(-54.10deg,90.00deg,-26.57deg) * trans(19.81cm,139.89cm,75.97cm)
distance: (-152.63cm,-45.20cm,-19.81cm) 160.42cm
measure_distance():

```

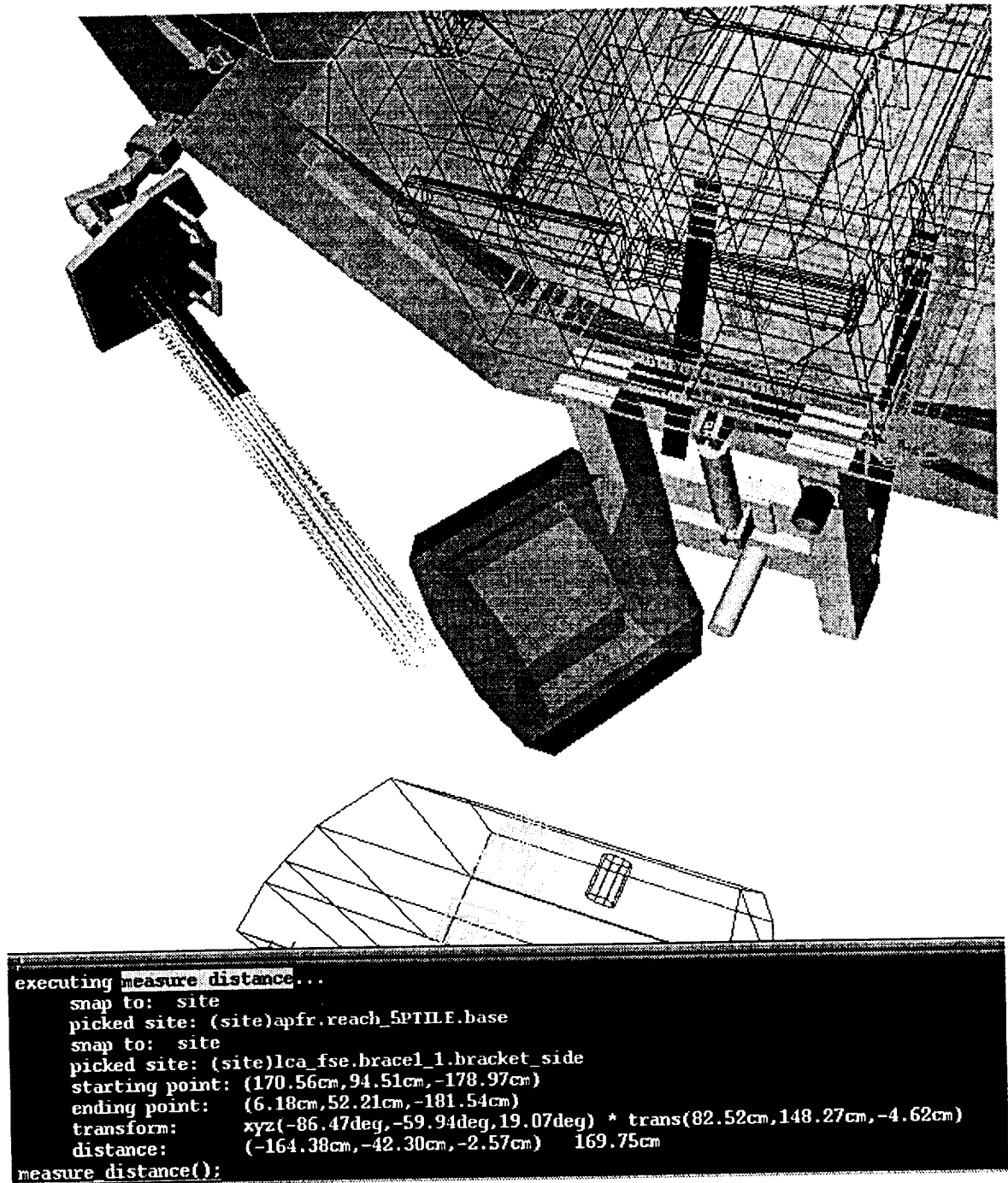
File No. F2-LC1

Figure 5.2.1-21 Removing the Starboard LCA Securing EVA Bolt (LC1) from Position F2.



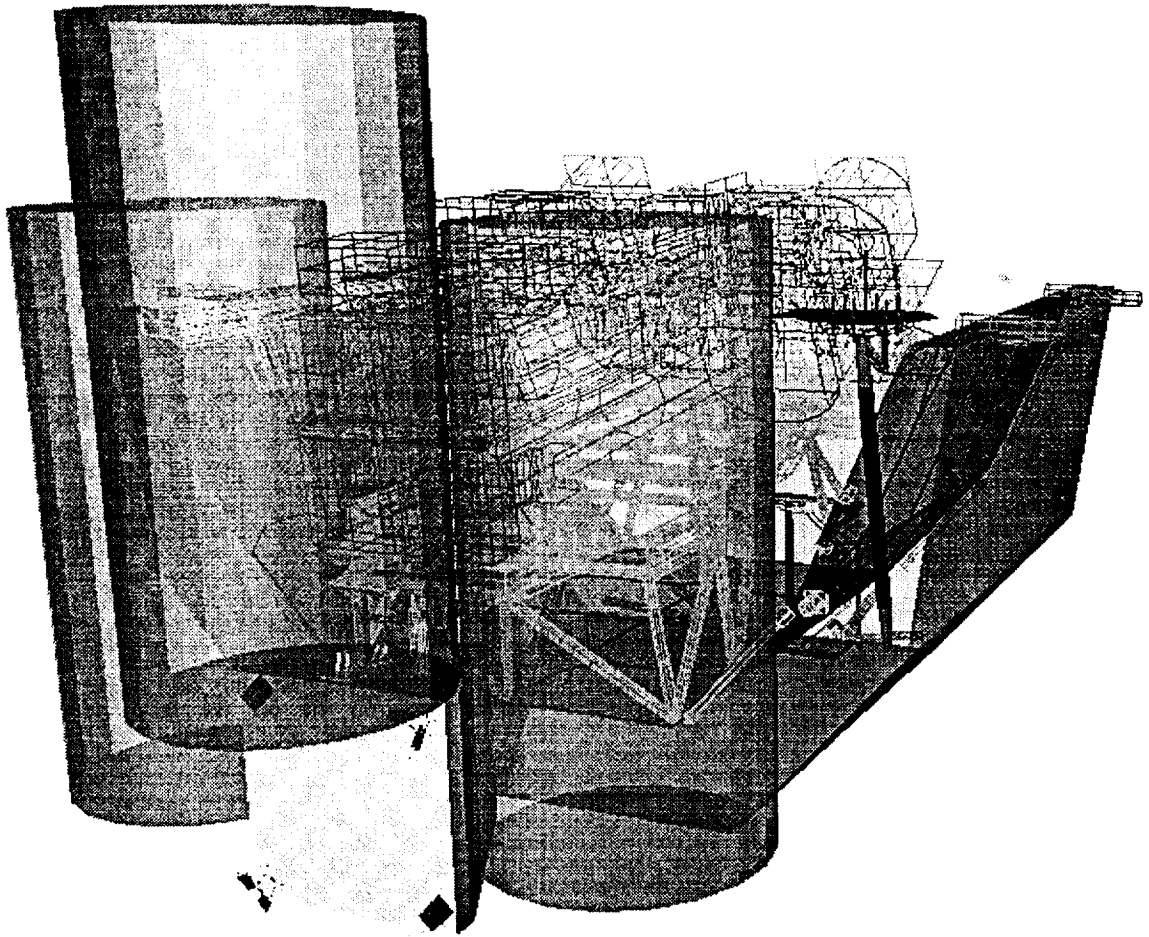
FILE No. F4-LC2

Figure 5.2.1-22 Removing the Top LCA Securing EVA Bolt (LC2) from Position F4.



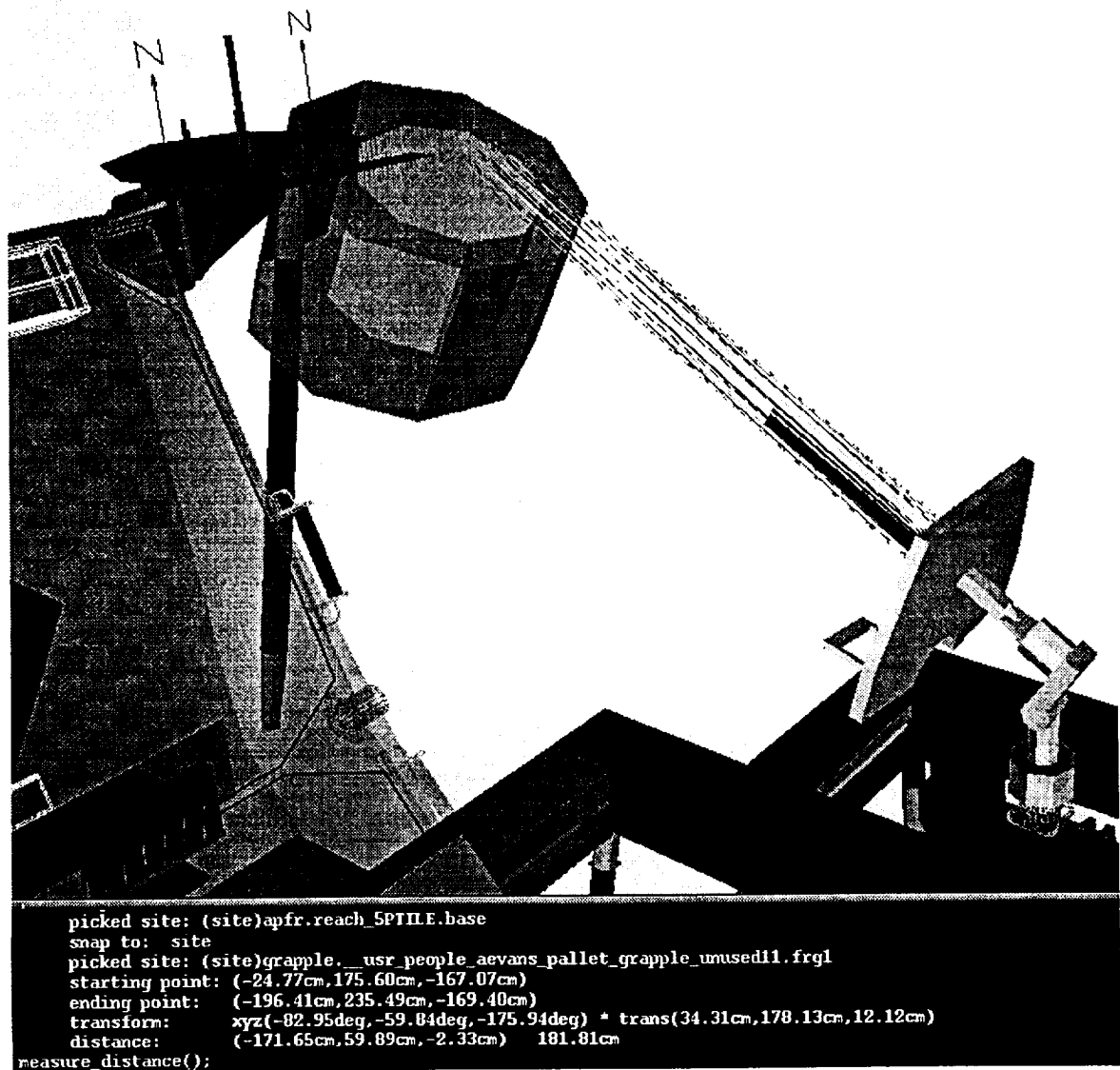
FILE No. F2-LC4

Figure 5.2.1-23 Securing Strut for LCA (LC4) After Removal of LCA from Stowage from Position F2. (The unstowed LCA can be seen in the foreground.)



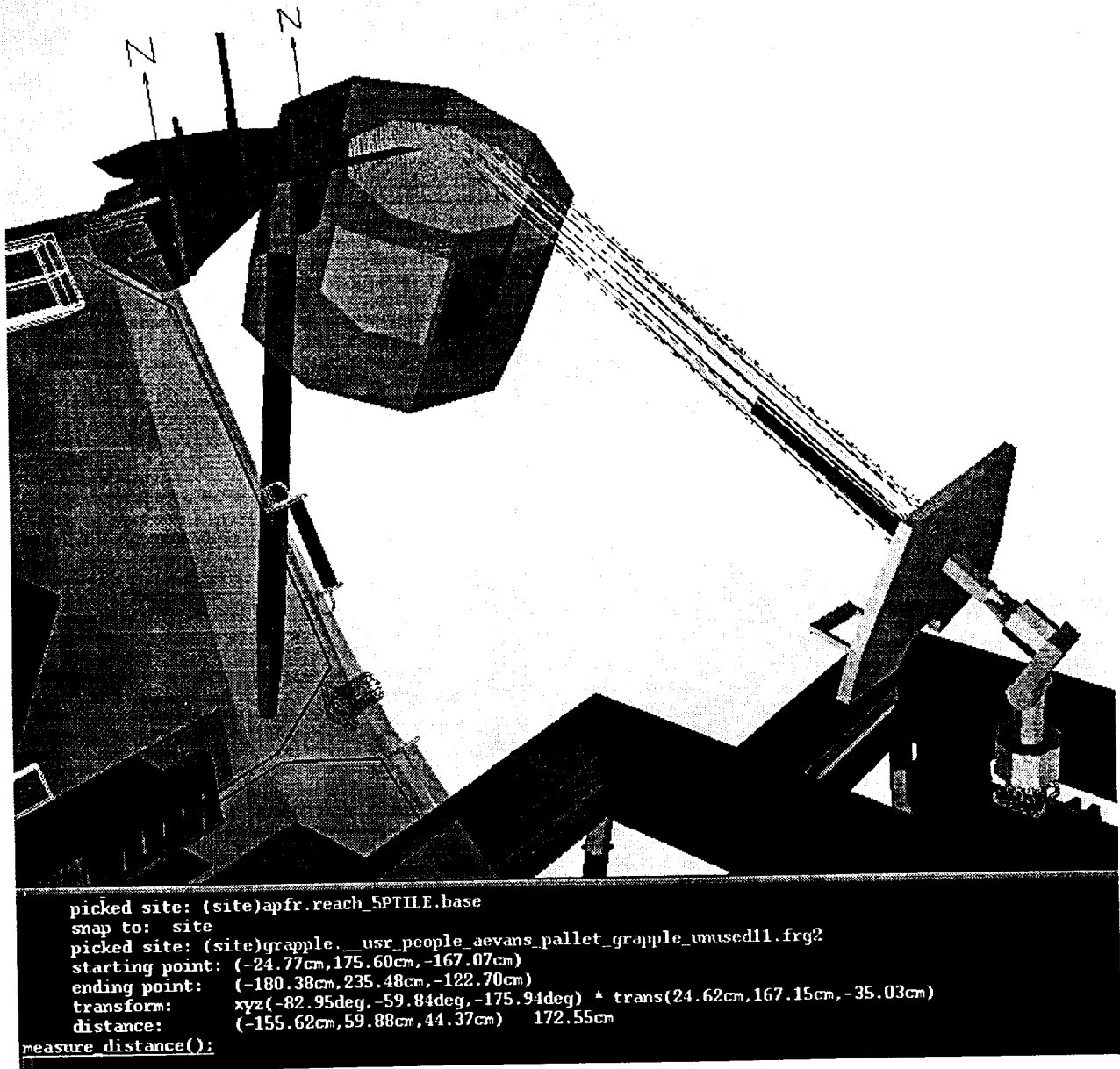
FILE No. FWD-WORK-ENV

Figure 5.2.1-24 Accessing LCA Worksites LC1, LC2, LC3, and LC4 From a PFR on the SRMS. (Shown is the required 48" diameter work envelope).



File No. F5-FRG1

Figure 5.2.1-25 Accessing the Forward EVA Release Mechanism (FRG1) on The FRGF From an APFR at Position F5. (The SSRMS has been raised/deployed).



File No. F5-FRG2

Figure 5.2.1-26 Accessing the Aft EVA Release Mechanism (FRG2) on The FRGF From an APFR at Position F5. (The SSRMS has been raised/deployed).

5.2.2 Body Clearance Envelope:

The clearance envelopes for the space-suited subject was not considered an issue for most tasks; the exceptions being loosening the forward EVA bolt on the PDGF Rigid Umbilical (task RU1) and unlatching the hook-links on the FSEGF (HL1 and 2). An adequate amount of space afforded by the geometry of the LDA for each of the WIF positions, with the noted exceptions.

Clearance for task RU1 was not assessed through the use of the Jack software, but was judged to be within the reach of a human subject. In fact, the Neutral Buoyancy Development Test supported this contention. The subjects were able to reach the worksite by proper orientation of the APFR.

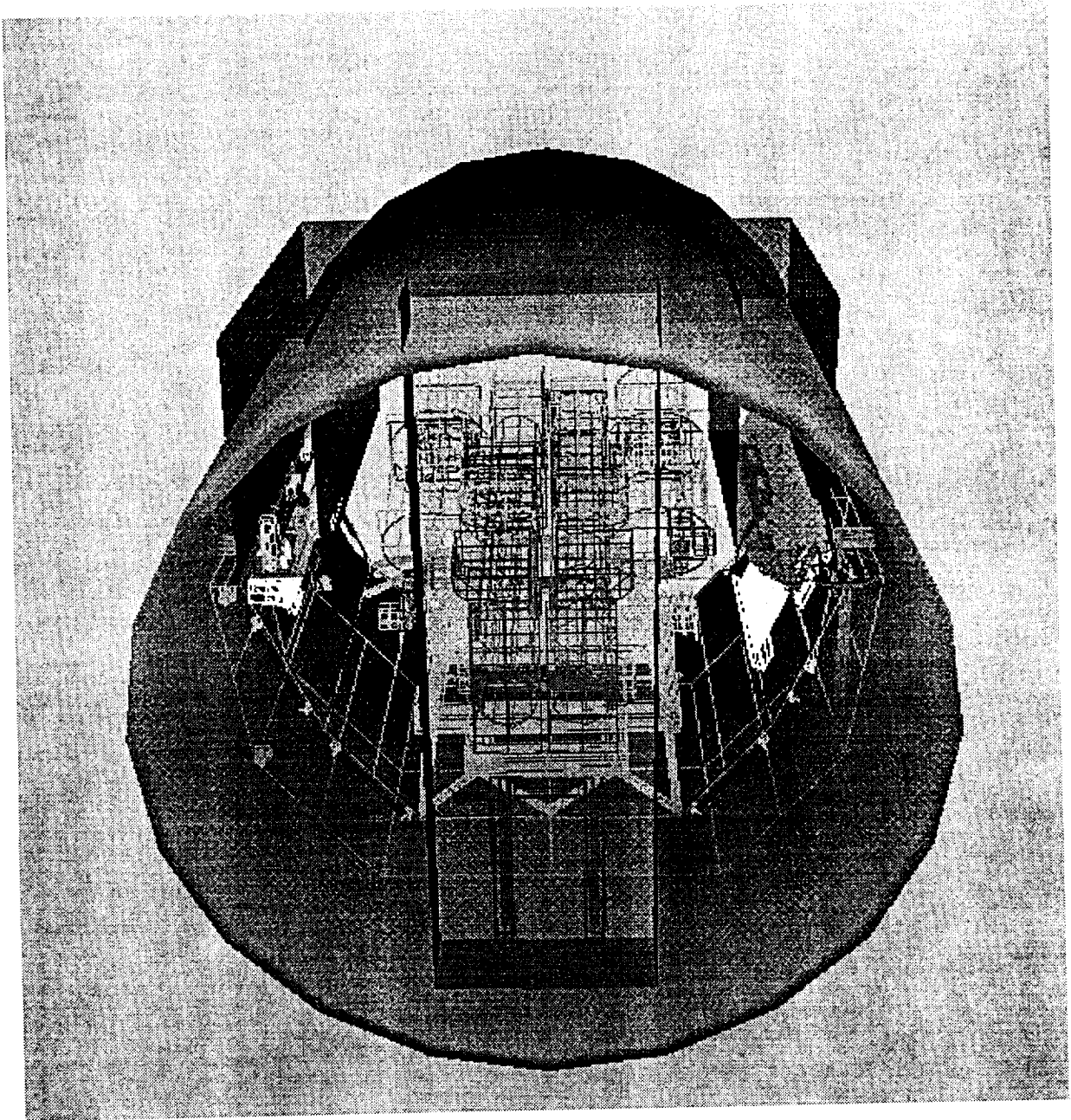
Clearance for unlatching the hook-links (HL1 through 4; sides are symmetrical) afforded more than adequate room as seen in Figures 5.2.1-10 and 5.2.1-11.

5.2.3 Tool Clearance Envelope:

Tool clearance was determined by the model to be more than adequate. The geometry of the LDA afforded ample room for full manipulation of a ratchet wrench or power tool as seen in the previous illustrations.

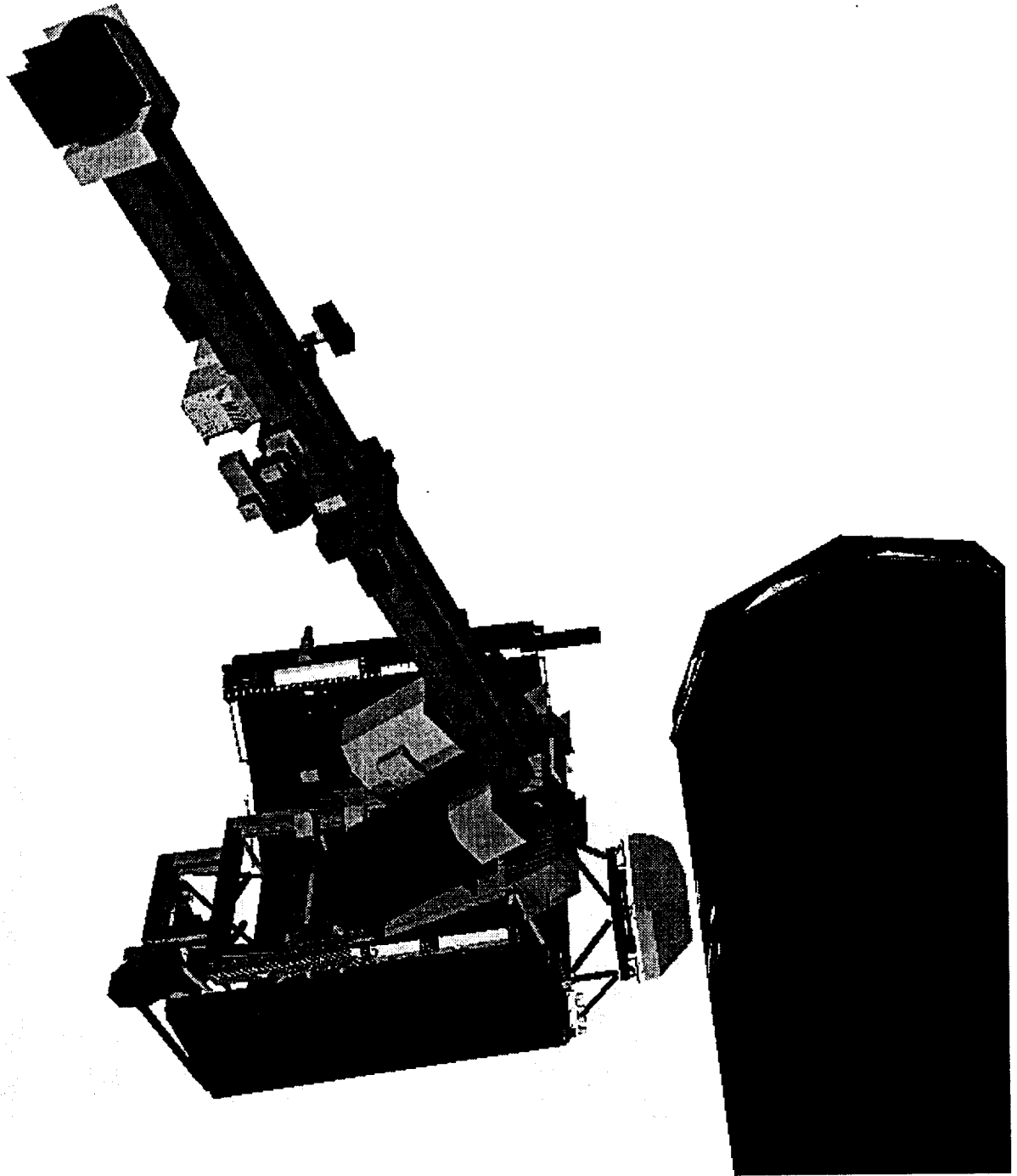
5.3 CARGO REMOVAL ENVELOPES:

Figure 5.3-1 illustrates the removal envelopes for the PDGF Rigid Umbilical, UHF Antenna Assembly and LCA. Each is represented by the maximum envelope size obtained from the Cargo Item Developers. All three items are shown being lifted in a +Z_p direction after clearing the associated mounting interfaces. In the case of the PDGF Rigid Umbilical this would mean lifting the item to clear the mounting blocks < 6" and then +Z_p. The LCA is shown being brought forward (-X_p) approximately 6" to clear the attachment fixture on the LSA and then lifting in a +Z_p direction. Forward clearance between the LCA and the Airlock is 85", which exceeds the minimum of 48" by 31" when the LCA is moved 6" in the -X_p direction.



FILE No. CRE-F

Figure 5.3-1 Cargo Item Removal Envelopes from the SLP Envelope. On the Left (Port) is the UHF Antenna, the Right Side (Starboard) is the PDGF Rigid Umbilical, and the center is the envelope of the Lab Cradle Assembly. (View from Forward looking Aft).



FILE NO SSRMS-RAISED

Figure 5.3-2 SSRMS Booms Raised $\sim 80^\circ$ Prior to Stepping Off Operations. The Launch Deployment Package is Mated With the Lab Module via the LCA/MTSAS-P. (Nadir View)

Figure 5.3-2 illustrates the position of the SSRMS Booms when raised into position for the stepping-off operations. This view illustrates the clearance from the SLP and associated mounting interfaces. The stepping-off operations are not under the purview of the LDA program.

5.4 Tie-down Bolt Stowage:

Figure 5.2-14 illustrates the position for manipulating the knob actuator on the Tie-down Bolt Stowage and Figures 5.2.1-15 through-17 illustrate the configuration for tightening the EVA bolts to secure the slider. The actuator is the knob located near the center of the slider and the EVA bolts can be seen toward either end of the structure near the cross hairs which designate the target site for measurement. The position of the APFR is the same as used for removal of the PDGF Rigid Umbilical (RU3). , and which were within acceptable limits of the calculated reach envelope (see Section 5.2.1). The center location for the actuator and EVA bolt (BC2 and BC3) were well within the two-handed reach envelope, while the EVA bolts at either end (BC1 and BC4) were slightly outside the two-handed reach envelope, but within the one-handed reach envelope. The use of a power tool or right angle drive would mitigate the problem, and will be tested in the Neutral Buoyancy Simulator.

5.5 SSRMS Clutch Manipulation:

Manipulation of the SSRMS clutches will be accomplished in free float, but the use of an APFR was investigated using WIF position A1 (A4 is a symmetrical candidate WIF position) Figure 5.2-13 illustrates the configuration of the APFR for this task. The calculated distance of 167.7 cm is outside of the two-handed reach envelope, by 3.5 cm, but well within the single-handed operational range of 113.5cm to 183.6cm (44.7"-72.3").

5.6 SSRMS Utility Cable Connector Removal from Dummy Connector Panel:

The location of the stowage area (dummy connector panel) for the connectors on the Utility Cable is located in the vicinity of the lower handrail on the Port side of the Aft end of the SLP. This location allows the use of standard SLP utility points to be used for attaching the panel bracket. In the previous analysis, the dummy connector panel had been located on a structural close-out panel located on the LSA. The new

location was analyzed to determine if the four connectors are within the grasp of a crew member located in WIF A1. Figure 5.1.2-18 illustrates accessing the approximate area of the location of the Dummy Connector Panel. The analysis indicates that the location used (near the end of the lower handrail) would place the connectors outside the two-handed reach envelope, but within the single handed reach envelope. This task also will be tested in the Neutral Buoyancy Simulator.

A separate analysis was performed on the feasibility of using a WIF on the Aft end of the SLP to mate the Utility Cable connectors with those located on the Lab Module. Figures 5.2.1-19 and 5.2.1-20 illustrate the results of this analysis. These two connector locations were chosen because they represent the two extremes of the four connector locations. The use of the WIF at A2 would seem feasible since the measured distances were 165.91cm and 139.37cm, within the two-handed reach envelope.

5.6.1 Glove Clearance Between Connectors on Dummy Connector Panel:

The spacing between connectors on the Dummy Connector Panel was analyzed to determine if an adequate amount of space was provided for EVA glove clearance. The four connectors are case size 25 and 25L. The widest measurement of the 25L connector was obtained from SSQ21635, Revision D and was determined to be 2.388". This measurement was subtracted from the spacing of the connectors on the Dummy Connector Panel as specified in Drawing 97M1967 (4.00"). The difference, 1.612", was greater than the minimum of 1.60" and was therefore acceptable.

5.7 LCA Unstow:

The design for stowing the LCA utilizes three EVA bolts which secure the LCA on either side and through the use of a strut on the top which swings down and is secured to the LCA adapter for landing. The two EVA bolts located on the top and on the Starboard side (LC2 and LC3) are expected to be released by a crew member on a PFR mounted to the SRMS. The EVA bolt on the Port side (LC1) is expected to be removed by the second crew member from a WIF position. The distance from the APFR center point to the EVA bolt location was measured for three locations: LC1, LC2, and LC4. The distance for LC1 was found to be within an acceptable reach (160.42cm- see Figure 5.2.1-21), but LC2 was outside the two-handed reach envelope with a

measured distance of 180.17cm (see Figure 5.2.1-22), but within the single-handed reach envelope of $113.5 < \text{Reach} < 183.6\text{cm}$. A measurement for distance was not made for LC3 because an inspection revealed no WIF which was an acceptable distance from the EVA bolt. LC3 will have to be removed by a crew member using the PFR/SRMS platform (PAD; PFR Adapter Device), although during a contingency operation, the LSA structure would possibly afford leverage for free float removal of the EVA bolt, depending upon removal torque values. Stowing the strut which secures the LCA during launch is illustrated in Figure 5.2.1-23 and was found to be within acceptable limits.

Access to all three EVA bolt locations to unstow the LCA (LC1, LC2, and LC3) can be accomplished through the use of a PFR/PAD combination on the SRMS as shown in Figure 5.2.1-24. The three vertical cylinders represent the 48" diameter required work envelope.

5.7.1 LCA Emergency Restow

In the event that the LCA must be restowed (*e.g.* an emergency deorbit), it estimated that two crew members could reattach the LCA to the LCA adapter in approximately 8:30 minutes. Table 5.7-1 illustrates the estimated EVA timeline.

Table 5.7-1 EVA Timeline for Emergency Restow of LCA On the LDA Mounting Adapter.

EV1	EV2	Task Description	EV1 Time	EV2 Time	Elapsed Time
EV1		Install and Ingress APFR	3:30		3:30
	EV2	Unstow LCA Launch Strut		1:30	3:30
EV1	EV2	Position LCA on Trunnion	2:00	2:00	5:30
EV1	EV2	Unstow two EVA Bolts	1:00	1:00	6:30
EV1	EV2	Reinstall two EVA Bolts to Launch Position	1:00	1:00	7:30
	EV2	Reposition LCA Launch Strut and Reinstall EVA Bolt to Launch Position	1:00		8:30

5.8 EVA Access to FRGF

The release of the FRGF is a contingency operation which would be performed in the event that the SRMS end effector does not release the FRGF. Two EVA interfaces are located beneath the disk which when activated, retract pins securing the center "mushroom" which the SRMS grasps. Figures 5.2.1-25 and 26 illustrates the actuation of the EVA interfaces on the FRGF. In this case the SSRMS is in a raised position or has been removed from the LDP, allowing the WIF at location F5 to be utilized. Both EVA interfaces are within the one-handed reach envelope. The distances measured (71.6" and 67.9") do not take into account the extension of reach afforded by a power tool or a ratchet wrench.

5.9 Other EVA Considerations:

5.9.1 Crew Entrapment:

With a truss structure such as the LSA, the issue of crew entrapment is a concern. The danger of a space-suited crew-member is considered unlikely because:

- The tubular struts at either end of the LSA form triangular openings which are spaced a maximum of 35.4" at the base. Other struts impinge upon this area and thus provide a "keep-out zone" which would preclude the entrance of a space-suited person.
- None of the EVA operations require reaching within the LSA envelope. The operation which comes closest to entering the LSA envelope is loosening the Hook-links on the FSEGF. This activity will be performed with the SSRMS booms raised to a near vertical position. The FSEGFs are mounted on the top surface of the LSA.

5.9.2 Pinch Hazard During SSRMS Operations:

A pinch hazard exists in the hinge area of the booms when the SSRMS booms are unfolded. This hazard can be minimized by the following actions:

- Marking the area around the mating surfaces of the booms in an appropriate manner.

- Include instructions in the EVA Mission Operations for the crew-member nearest the hinge area to retreat to a safe distance when the booms are being unfolded and to remain until the latches have been verified to be secure.

5.9.3 Abrasion Danger to EVA Gloves From Launch Restraint Bolts:

EVA gloves require protection from abrasion and contusion from sharp objects including machined threads. The only instance where this is likely in the LDA configuration is in the hand-off of the Tie-down Bolts. The hazard exists from the crew-member coming into contact with the threaded ends of the bolts. This hazard can be eliminated by the following:

- Include instructions in the EVA Mission Operations for the crew-members to avoid the threaded portion of the Tie-down Bolts.
- Provide distinctive markings for a "keep-out zone" near the threaded portion of the Tie-down Bolts.
- The use of an APFR placed such that one crew member could pass a Tie-down bolt to another crew member who was either tethered in "free-float" or who utilized the PFR/PAD on to the SRMS will allow the hand-off of the Tie-down bolts with neither crew member touching the vicinity of the threaded portion of the Tie-down bolts.